3D cloud effects from an aircraft scanning radiometer and beyond…

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Two main instrument/measurement concepts are discussed here:

1 – The cloud scanner instrument:

Remote sensing (aircraft or satellite) retrievals of the vertical profile of effective radius and thermodynamic phase as a function of temperature and height

2 – The rainbow camera:

Retrievals of accurate liquid water droplet effective radius and distribution width

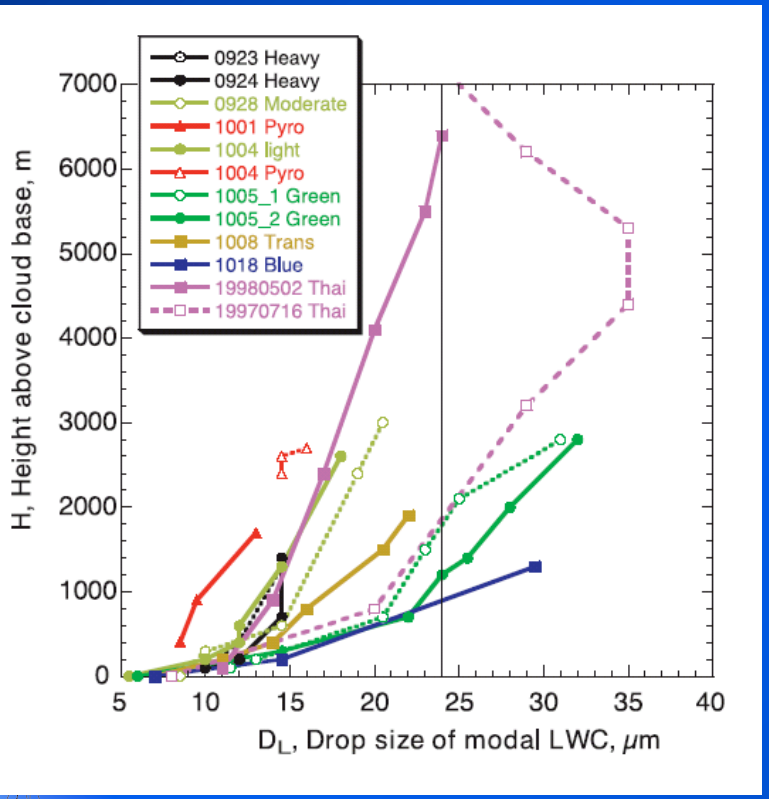
Preliminary results and simulations are shown for both cases.

In Situ Aircraft:

2004 Science Paper

Andreae, Rosenfeld, Artaxo, Costa, Frank, Longo, Silva- Dias:

Smoking Rain Clouds over the Amazon



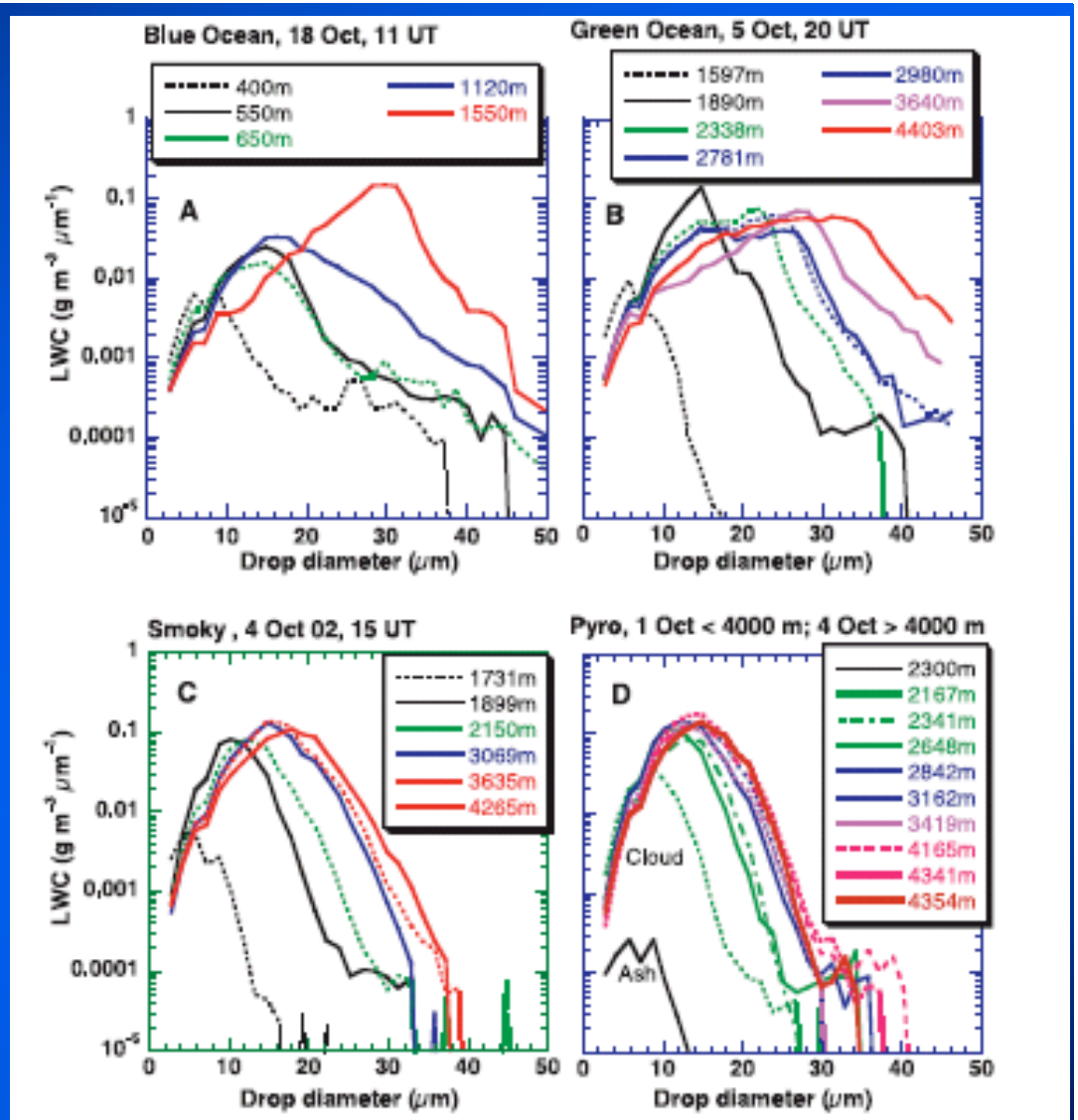


Fig. 4. The evolution of cloud drop diameter distribution (DSD) with height in growing convective clouds, in the four aerosol regimes of (A) blue ocean, 18 October 2002, 11:00 UT (universal time), off the northeast Brazilian coast (4S 38W); (B) green ocean, 5 October 2002 20:00 UT, in the clean air at the western tip of the Amazon (6S 73W); (C) smoky clouds in Rondonia, 4 October 2002, 15:00 UT (10S 62W); and (D) pyro-clouds, composite where douds at height <4000 m are from 1 October, 19:00 UT (10S 56W), and clouds above 4000 m are from 4 October, 19:00 UT (10S 67W). The lowest DSD in each plot represents conditions at cloud base, except in (D), where a size distribution for large ash particles outside of the cloud is also shown. Note the narrowing of CDSD and the slowing of its rate of broadening with height for the progressively more aerosol-rich regimes from (A) to (D).

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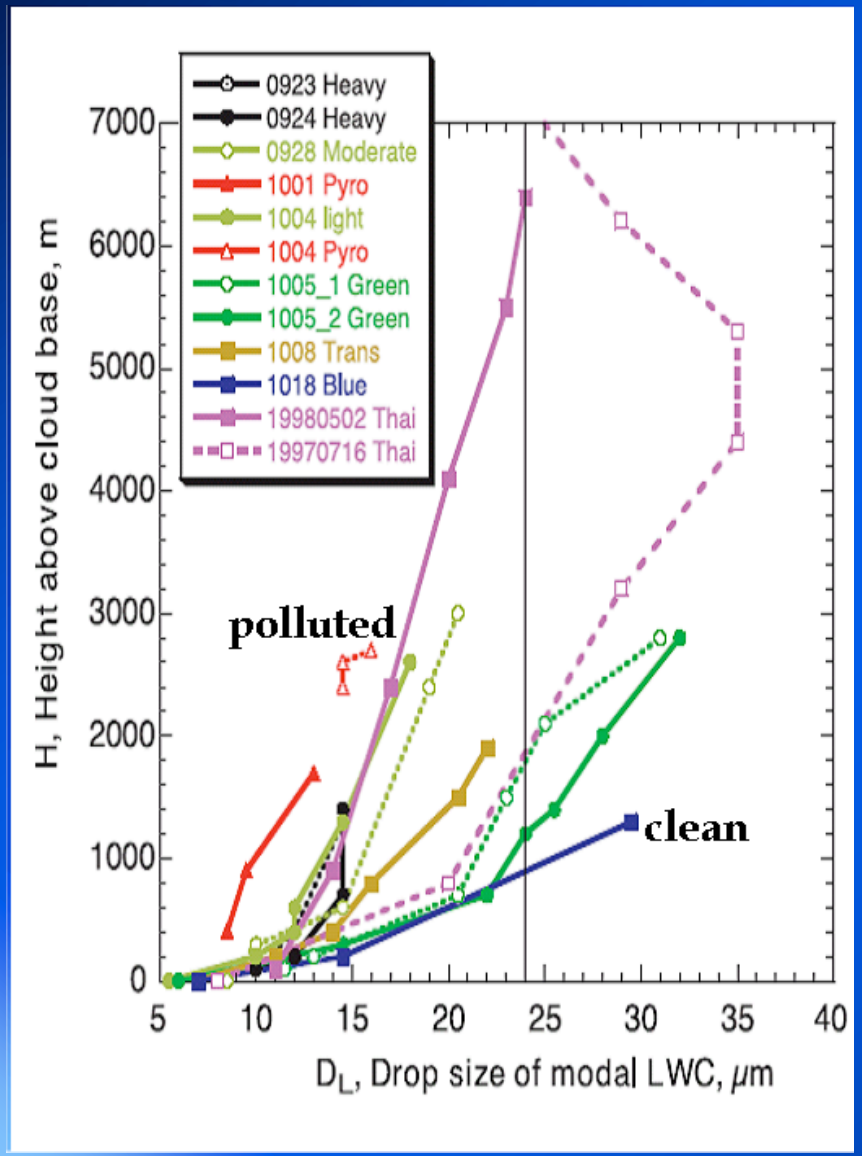
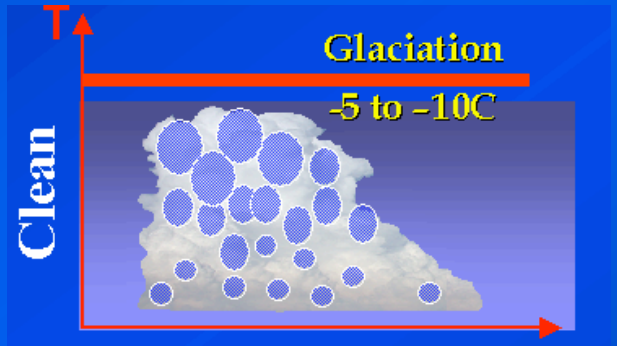
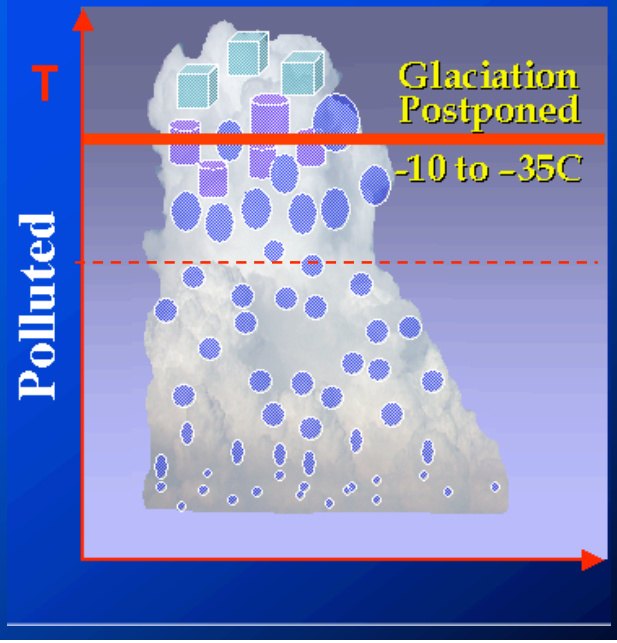
Smoking Rain Clouds over the Amazon



The Effect of Aerosol Particles in the Vertical Profile of Cloud Droplets Size, Phase, and Precipitation:



Vertical development, droplet size, glaciation, are directly affected by aerosol amount and type



In Situ Aircraft:

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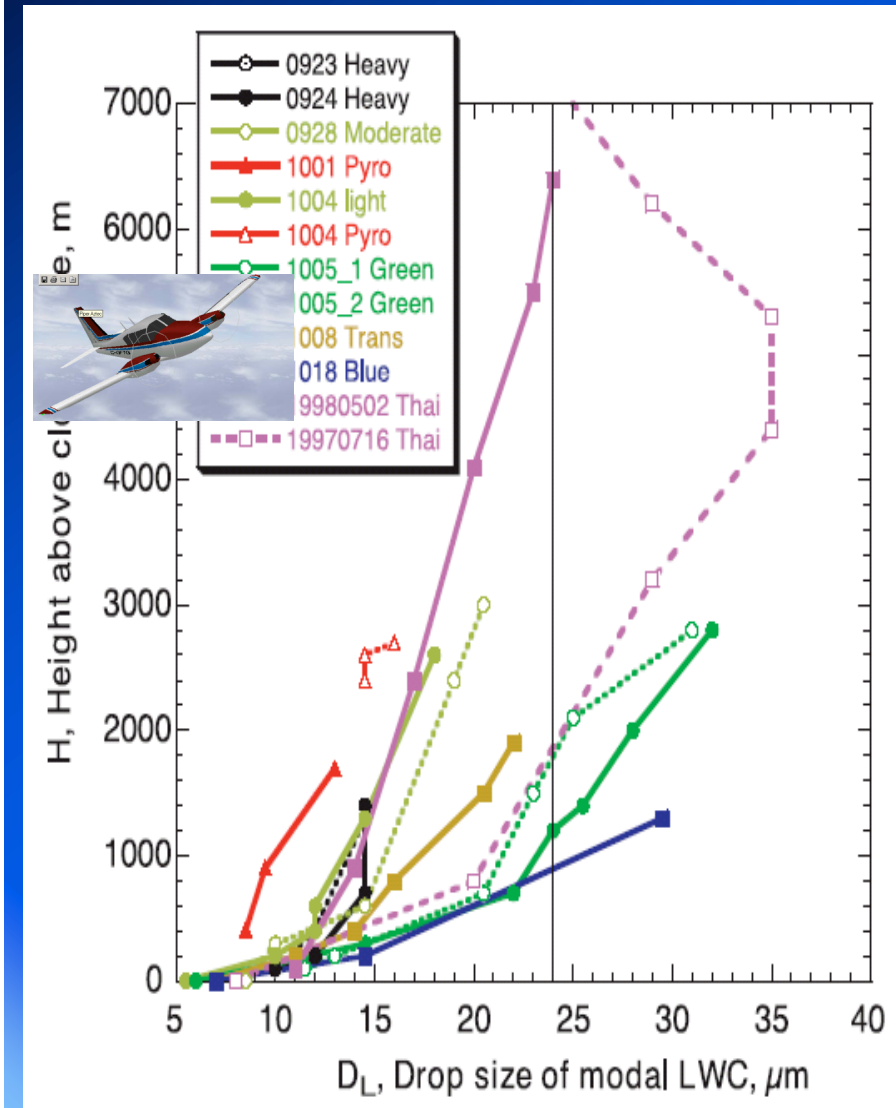
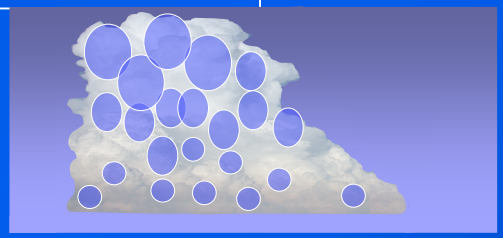


Clean Cases

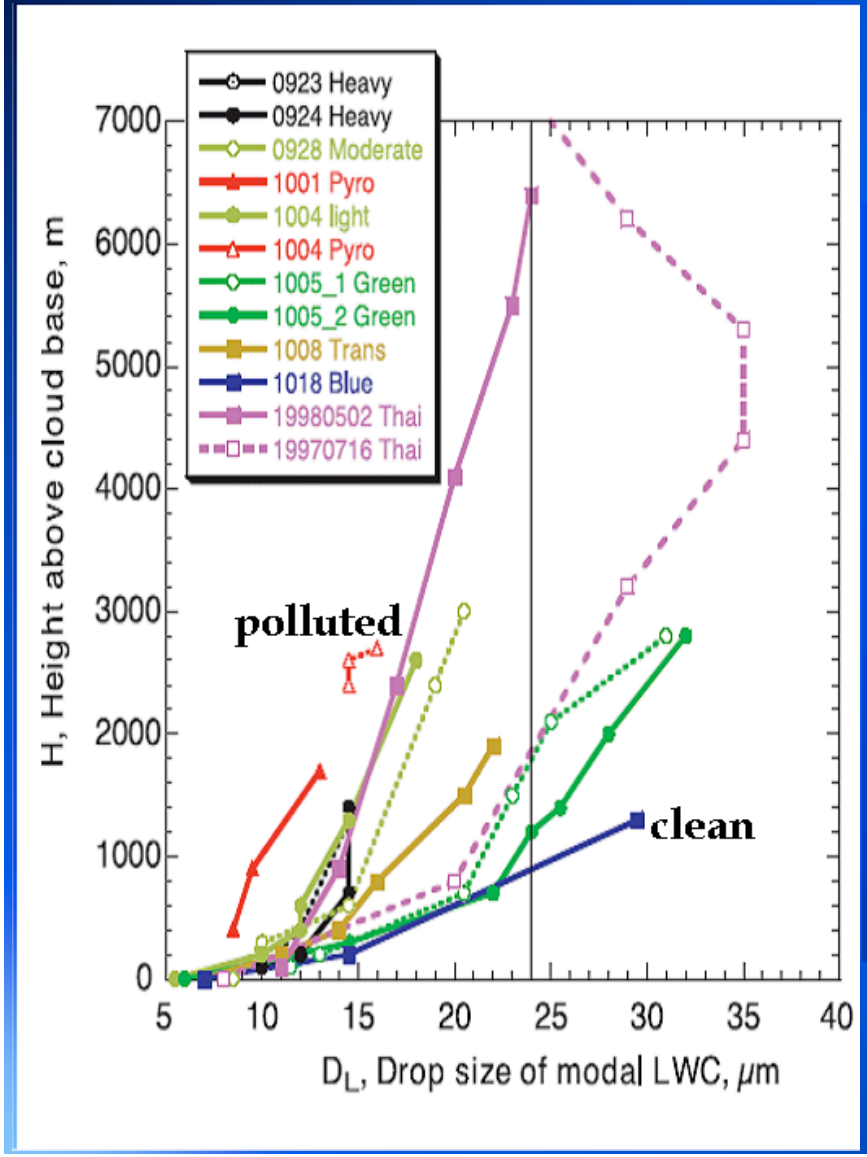


How detailed measurements are performed today…

Polluted Cases

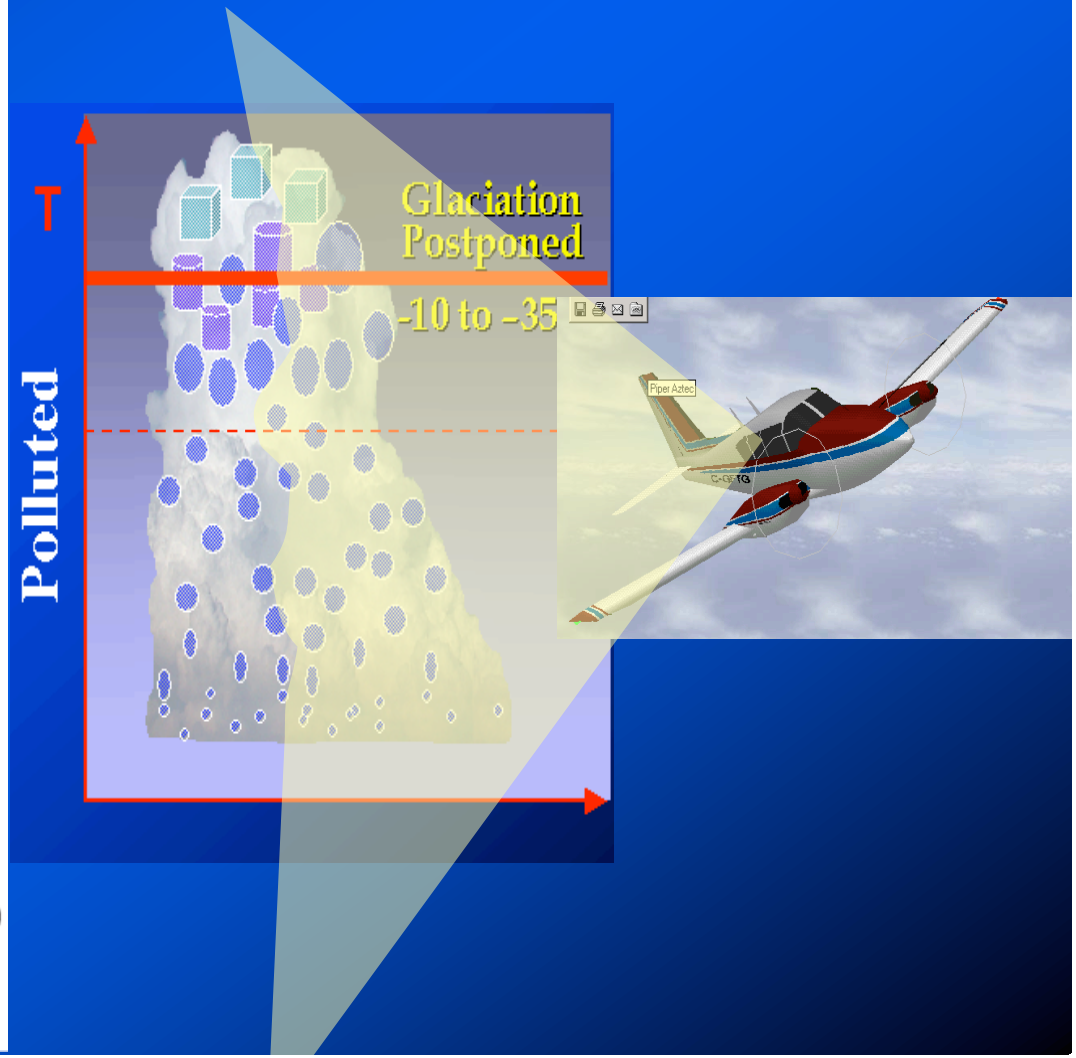
In Situ Aircraft:

2004 Science Paper
Andreae, et al.
Smoking Rain Clouds over the Amazon



Proposed Remote Sensing from Cloud Side:

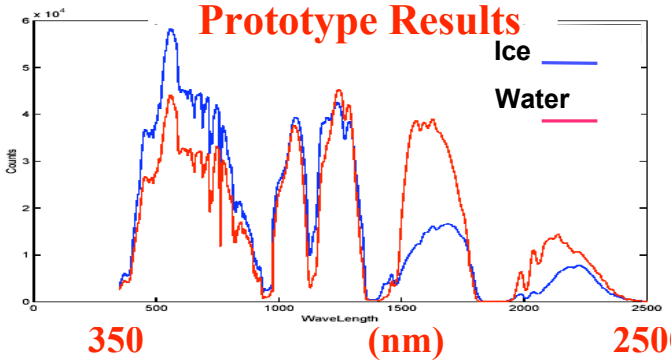
- Instantaneous profile of cloud droplet effective radius and thermodynamic phase



Cloud Scanner Measurements During the LBA/SMOCC/Racci Experiment 2002

Aircraft Proof of Concept

Cloud Side Measurements



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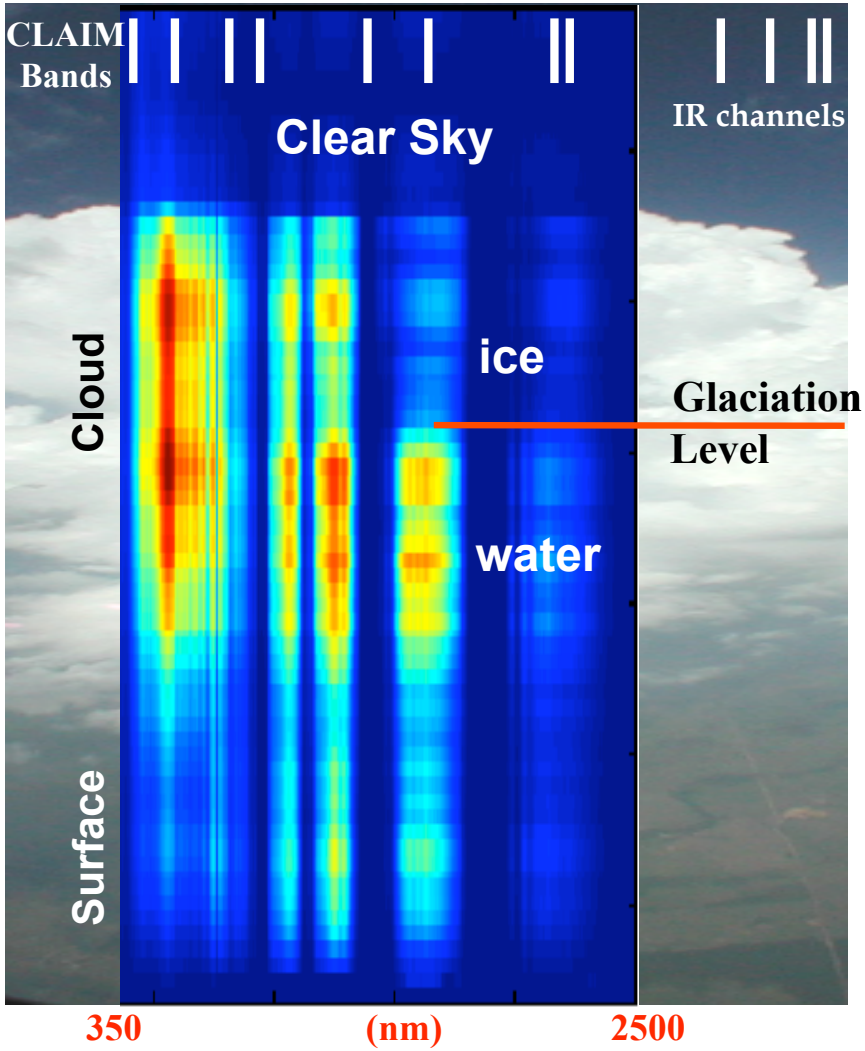
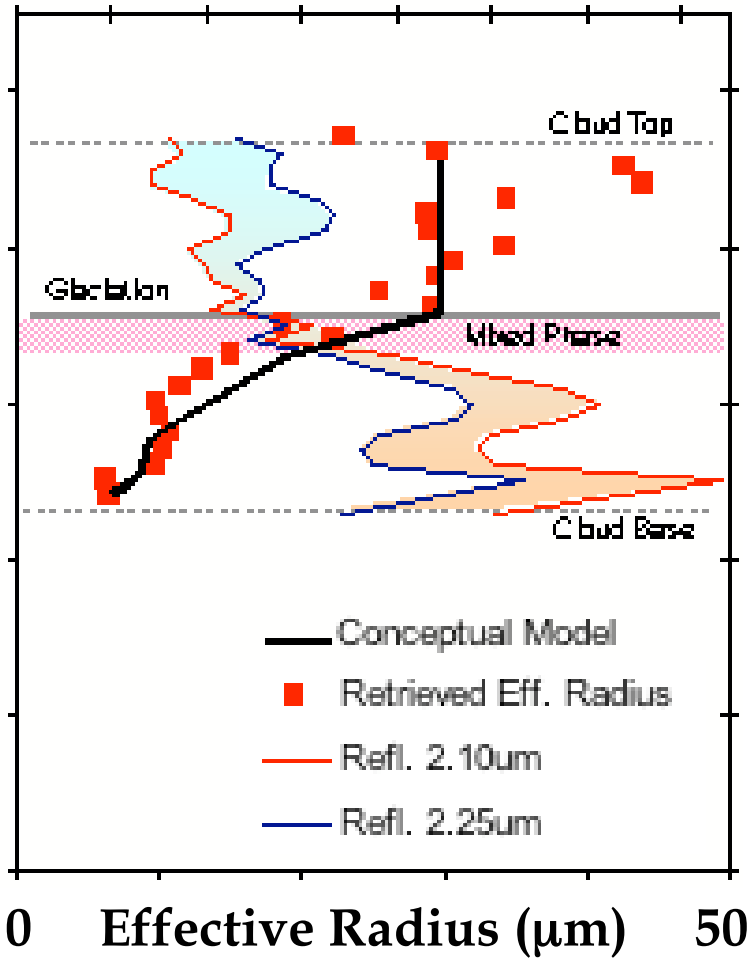
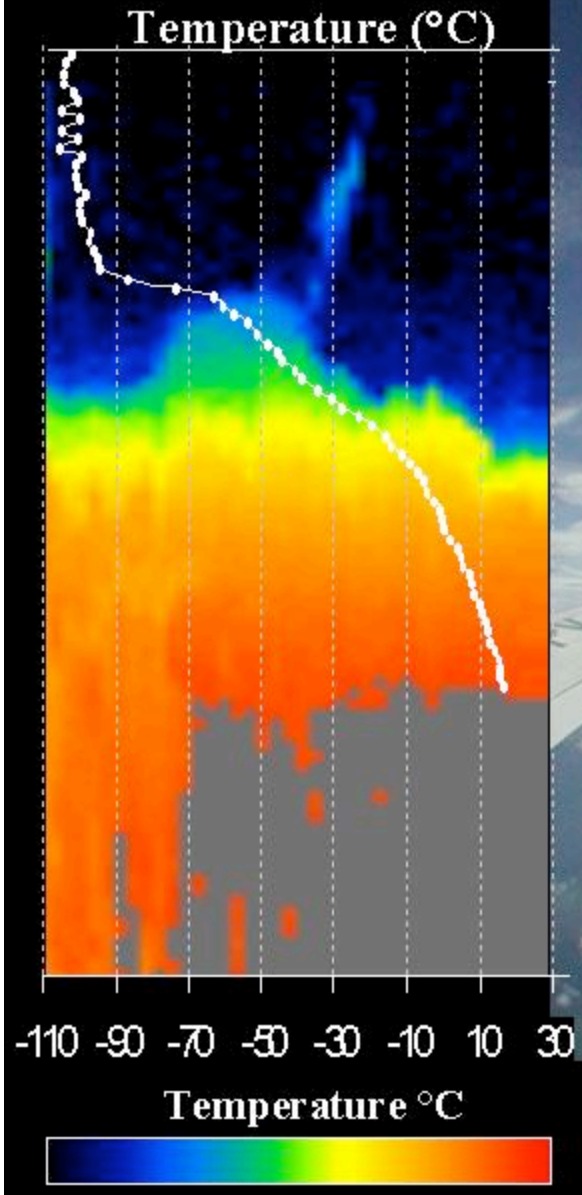
- Dro



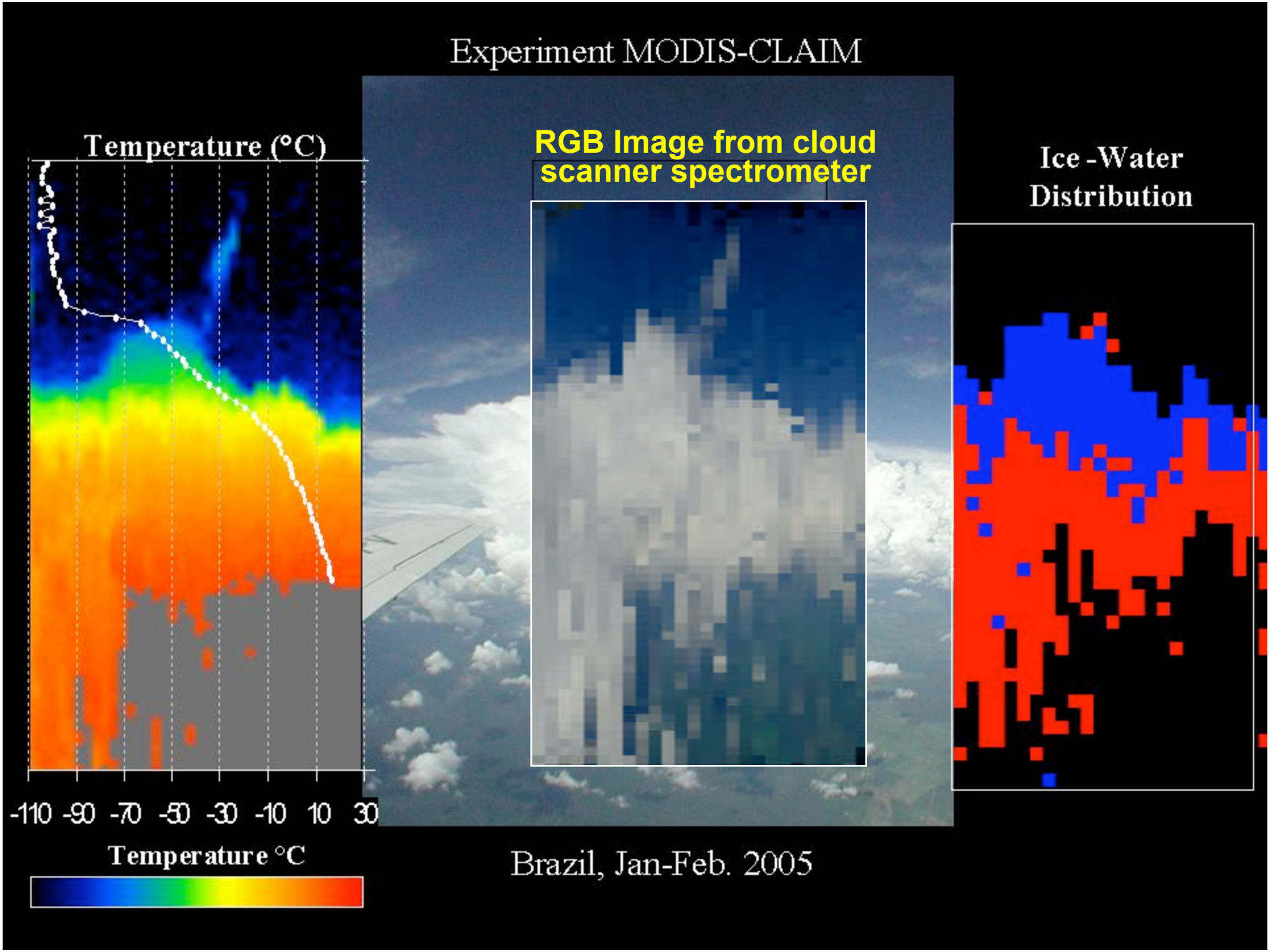


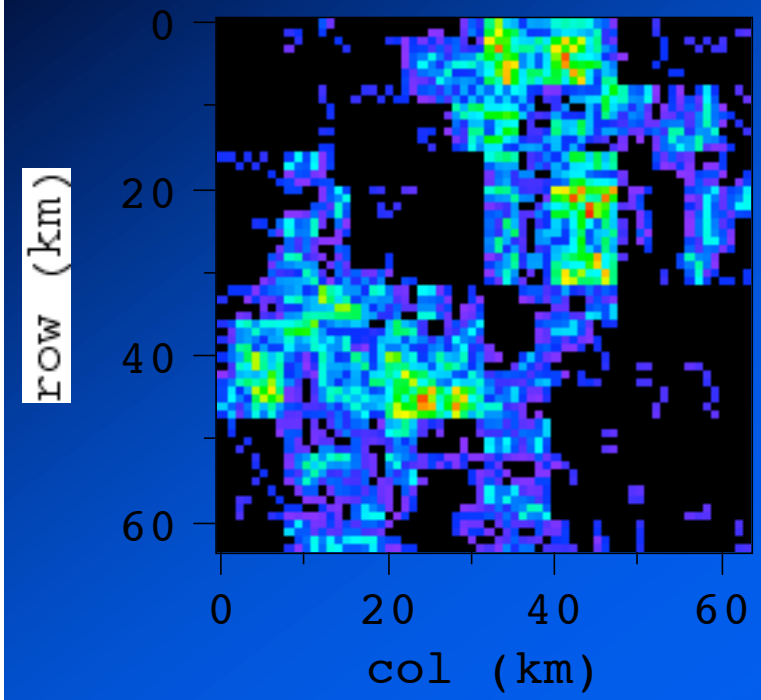
Experiment MODIS-CLAIM

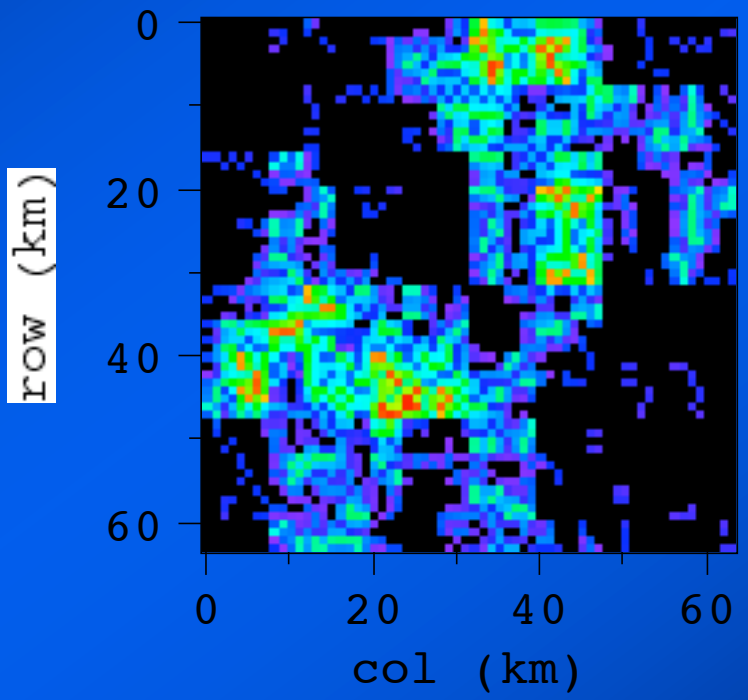
NASA/UMBC – IFUSP – INPE/CPTEC



Brazil, Jan-Feb. 2005


Experiment MODIS-CLAIM
Temperature (°C)
RGB Image from cloud scanner spectrometer
Ice -Water Distribution
-110 -90 -70 -50 -30 -10 10 30
Temperature °C
Brazil, Jan-Feb. 2005


row (km)
0
20
40
60
0
20
40
60
col (km)


row (km)
0
20
40
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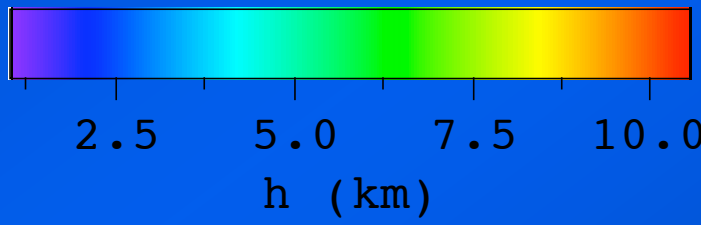
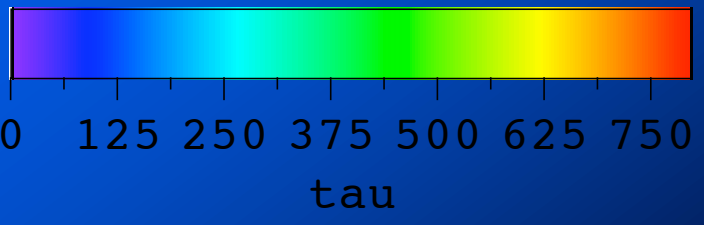
40
60
col (km)


2.5
5.0
7.5
10.0
h (km)


0
125
250
375
500
625
750
tau

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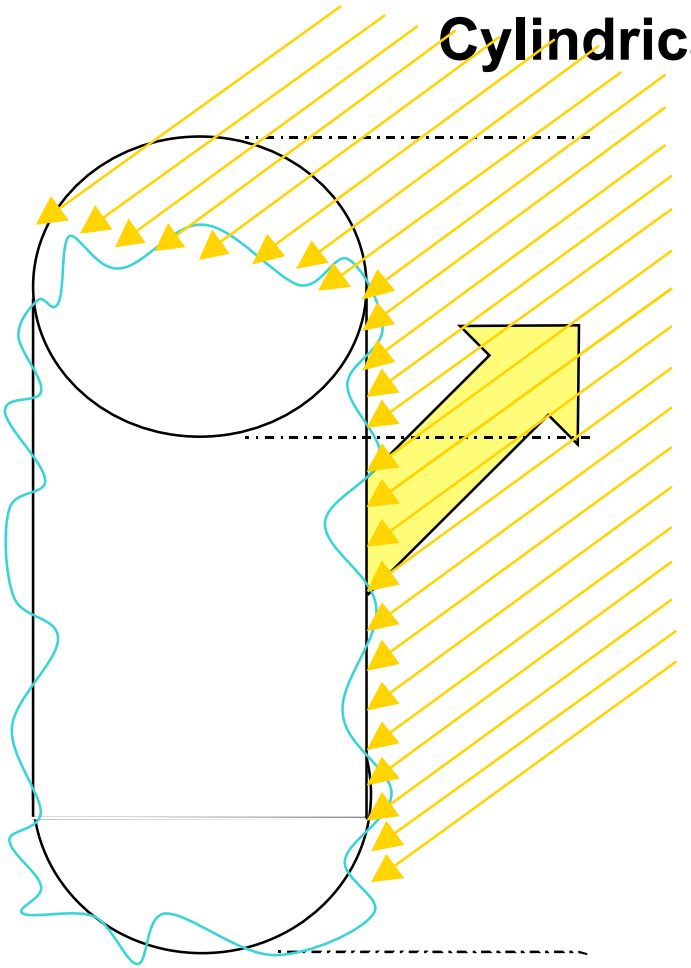
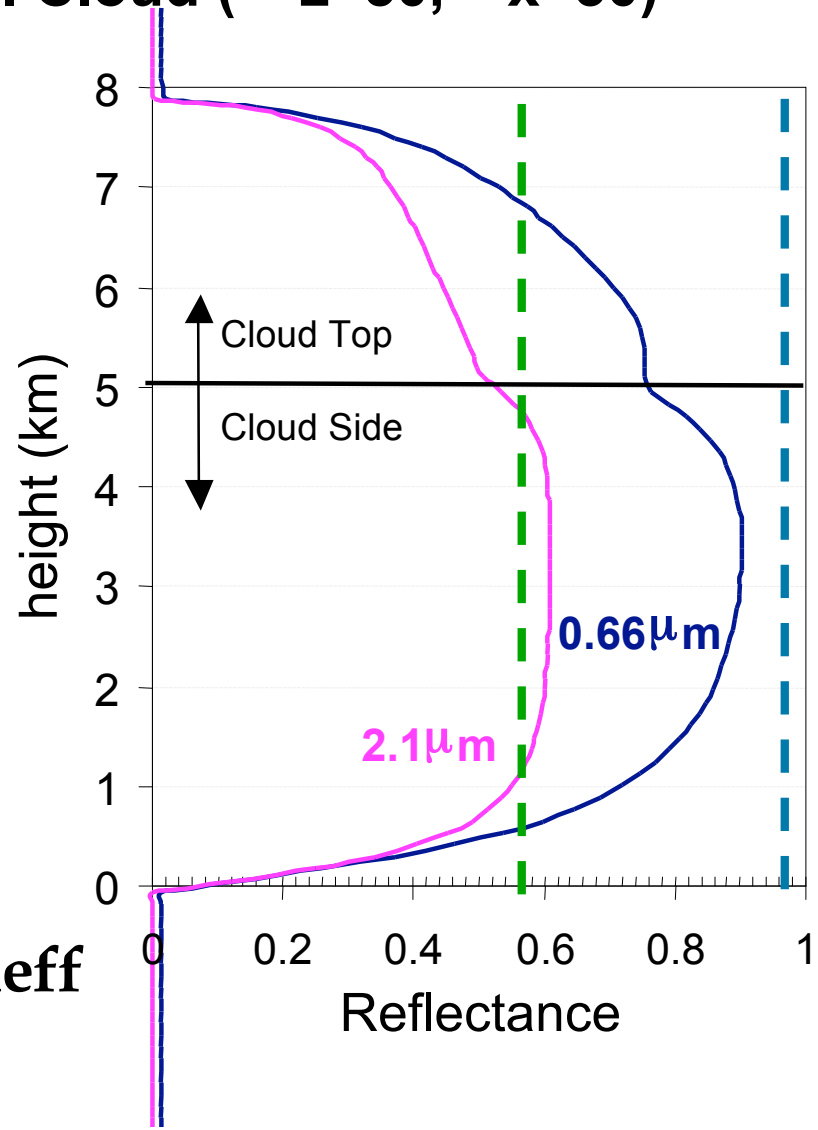
3-D Radiative Transfer Studies:

Reflectances from Side and Top of a Cylindrical Cloud ($\tau_{z=50}$, $\tau_{x=30}$)

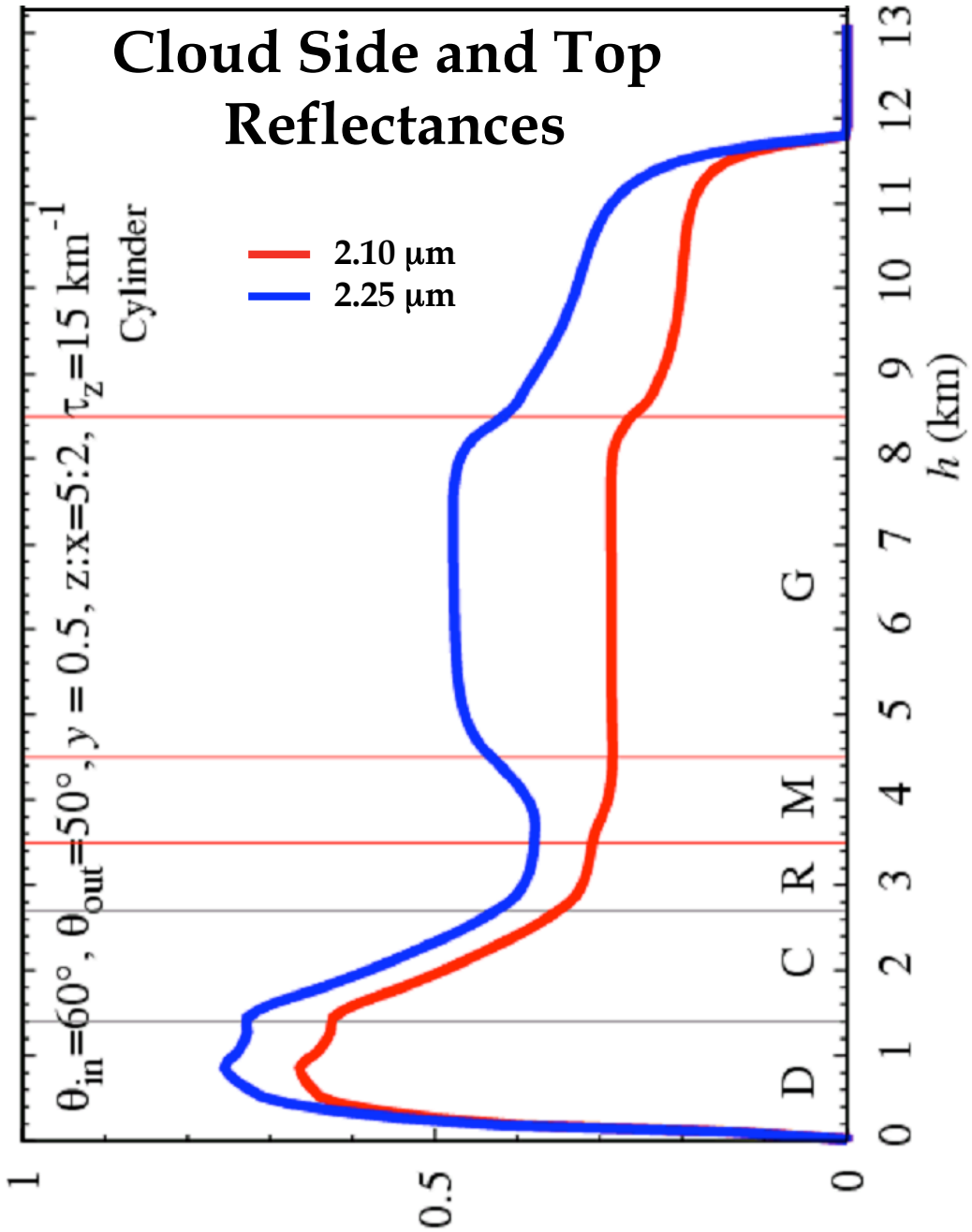


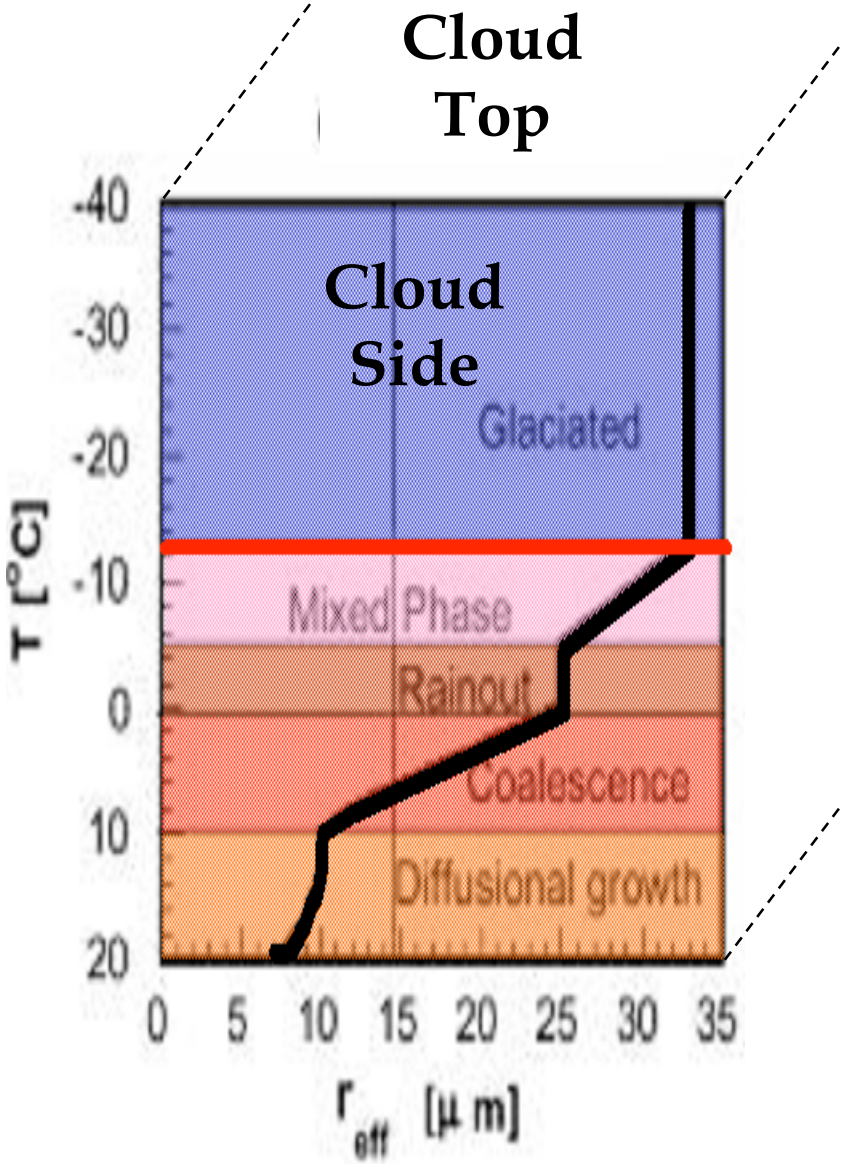
Homogeneous 10um Reff

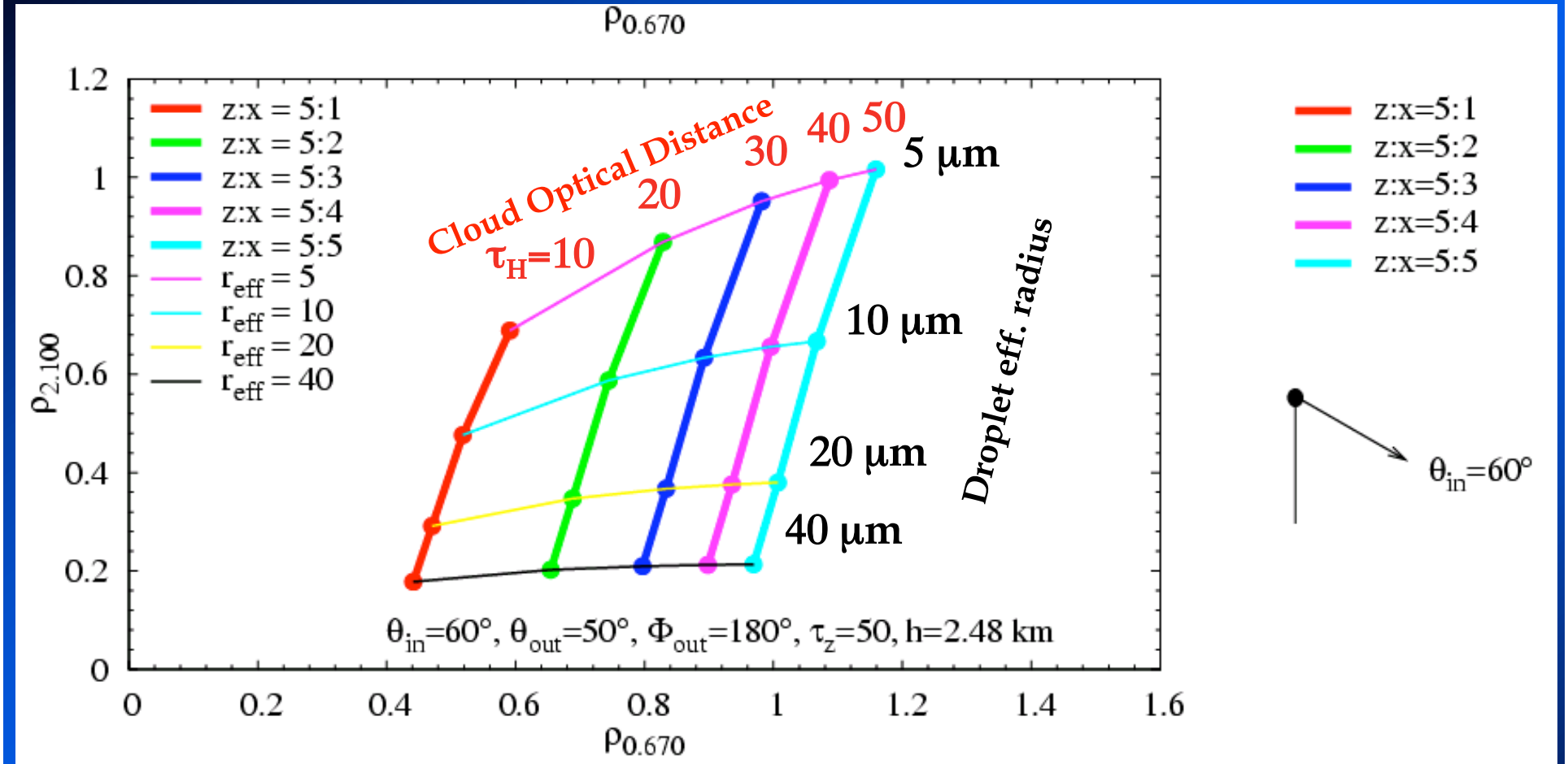


3D – RT Simulations

(individual clouds and complex cloud fields)





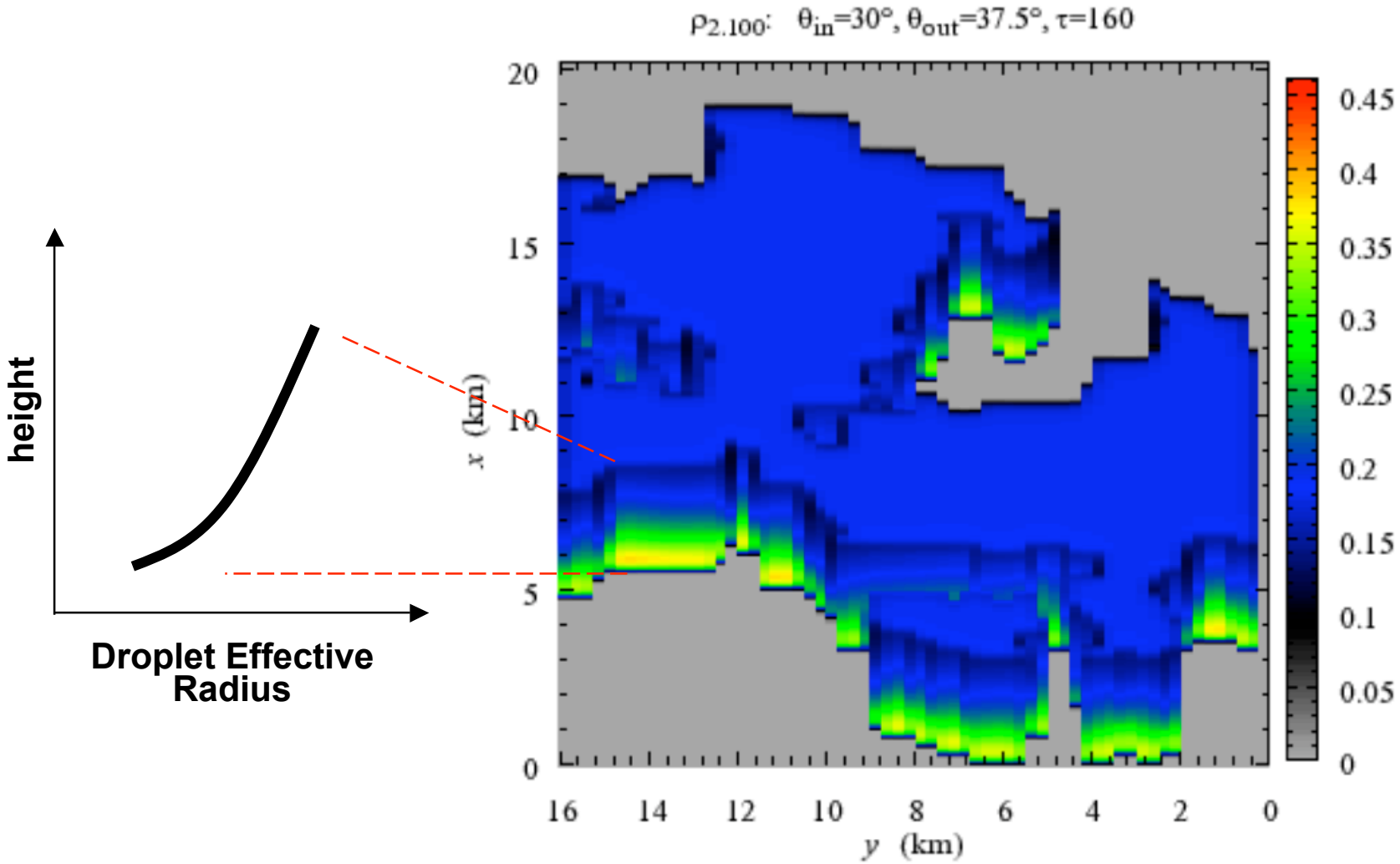


3D SHDOM Look up tables extending the Nakajima and King diagrams to 3D clouds observed from the side

3D Cloud Field Simulation

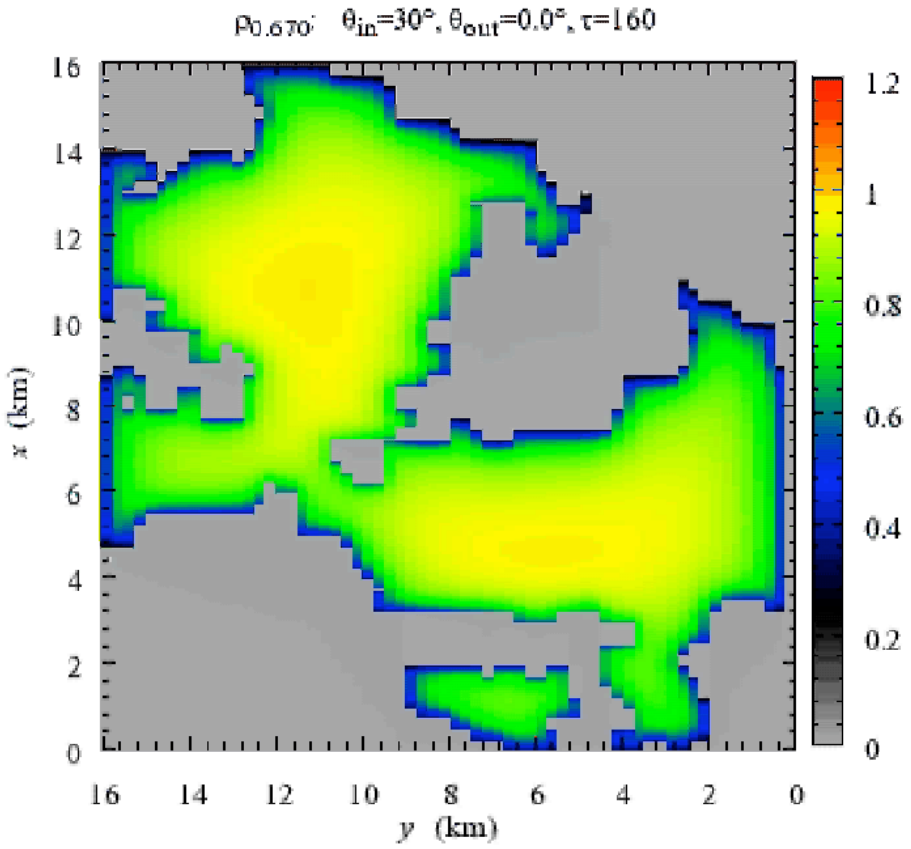
Reflectances at 2.1μm

V. Zubko, A. Marshak, J. V. Martins

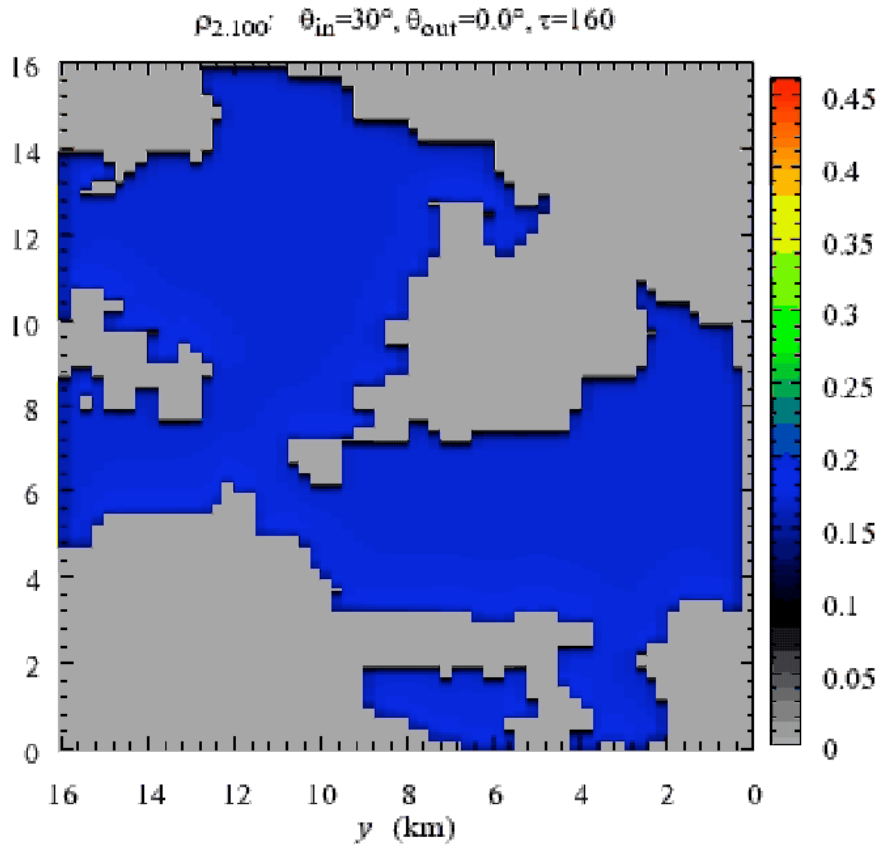


3D Simulation of Radiances from a Cloud Field using SHDOM:

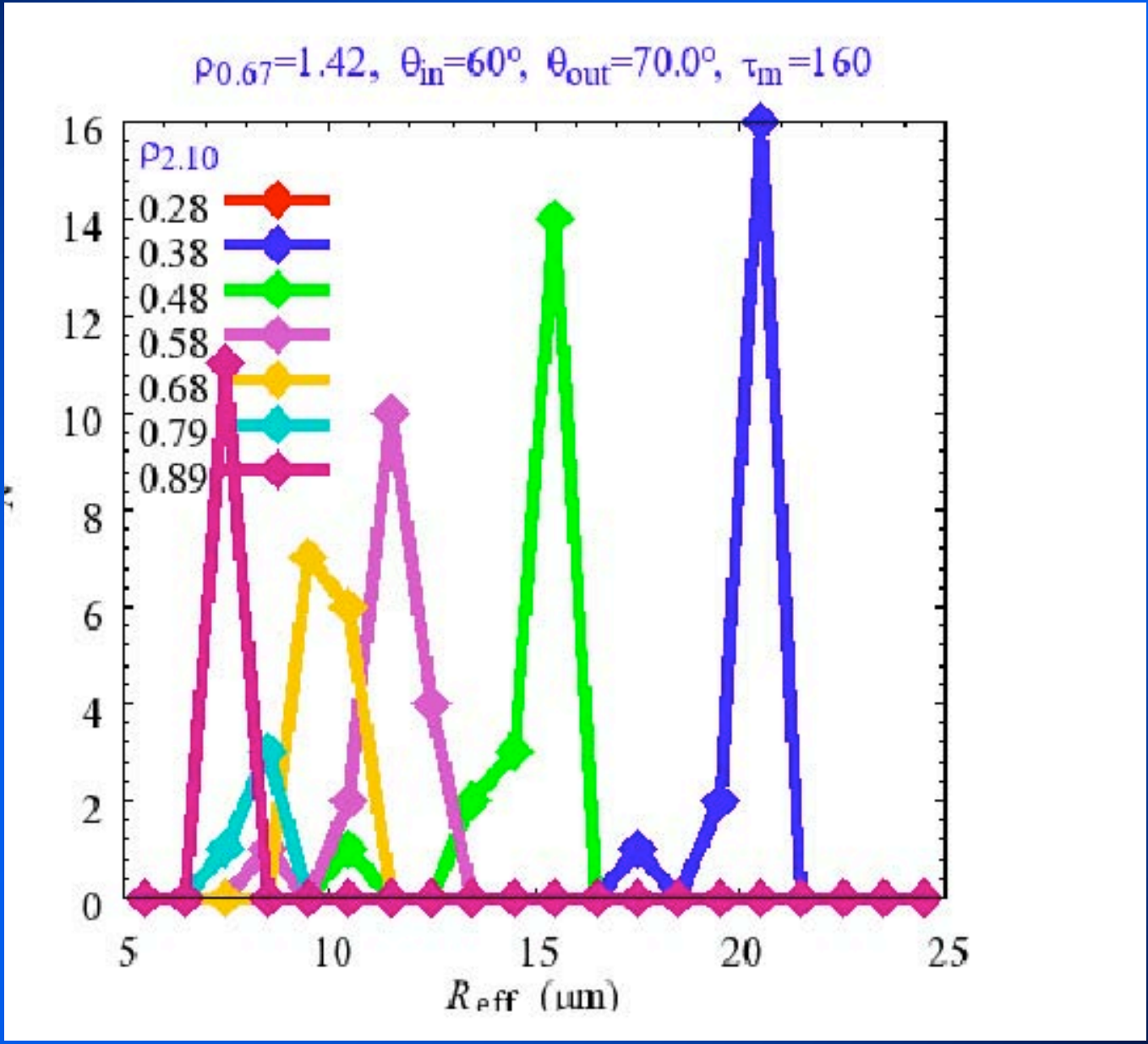
0.67μm



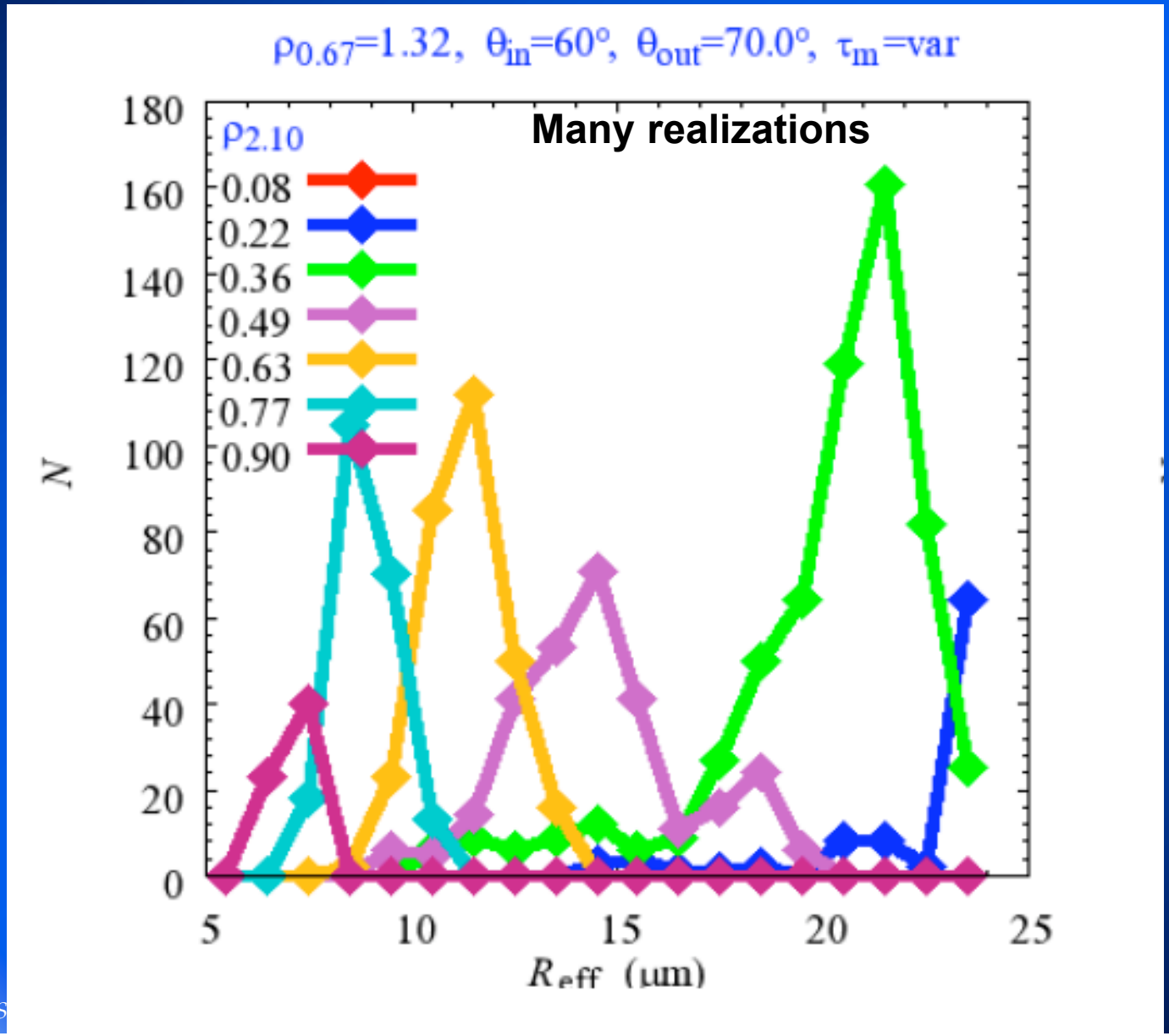
2.1μm



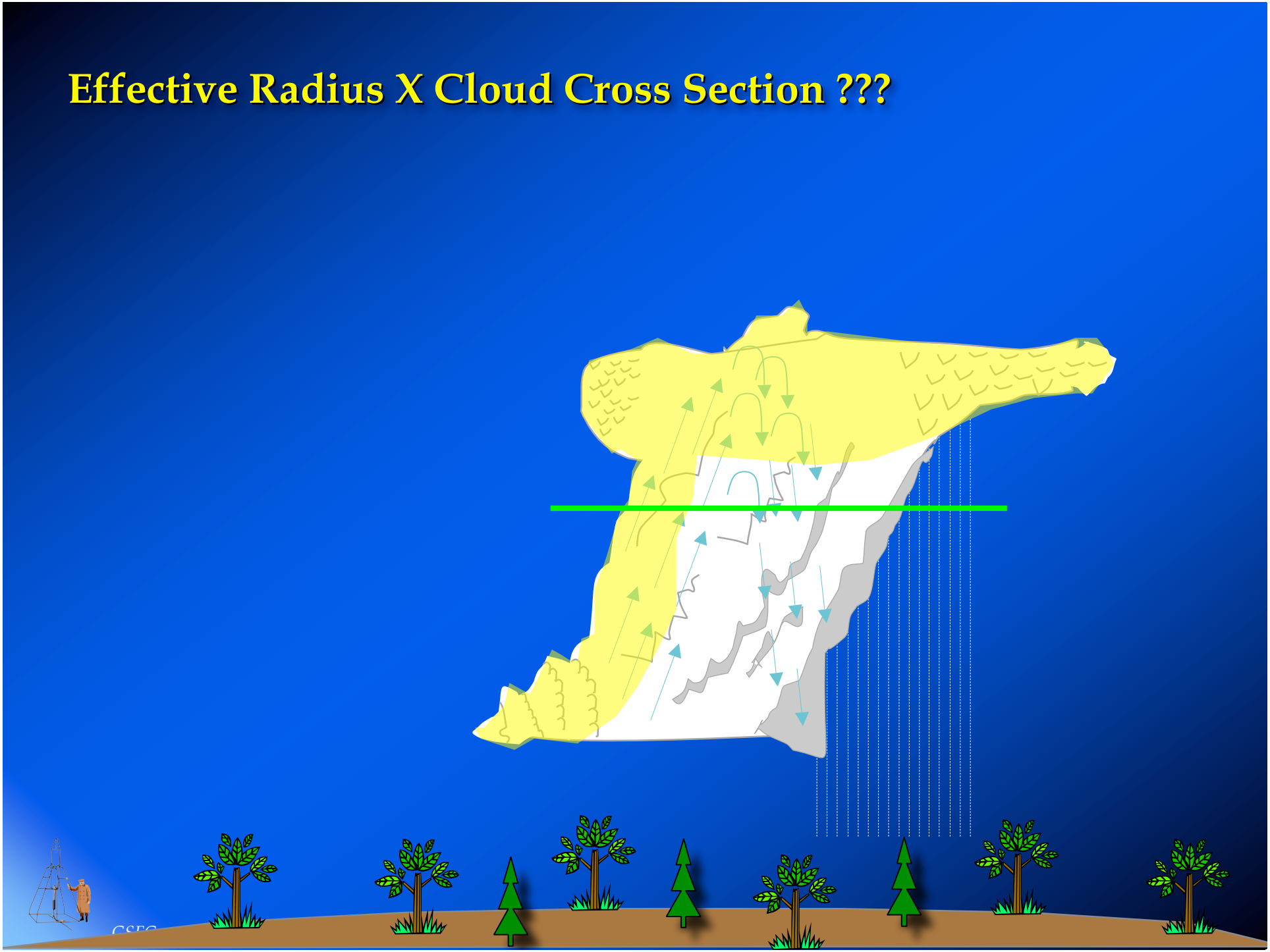
Histogram of Droplet Effective Radii as a Function of 2.1mm Reflectance Showing sensitivity for retrievals from cloud side



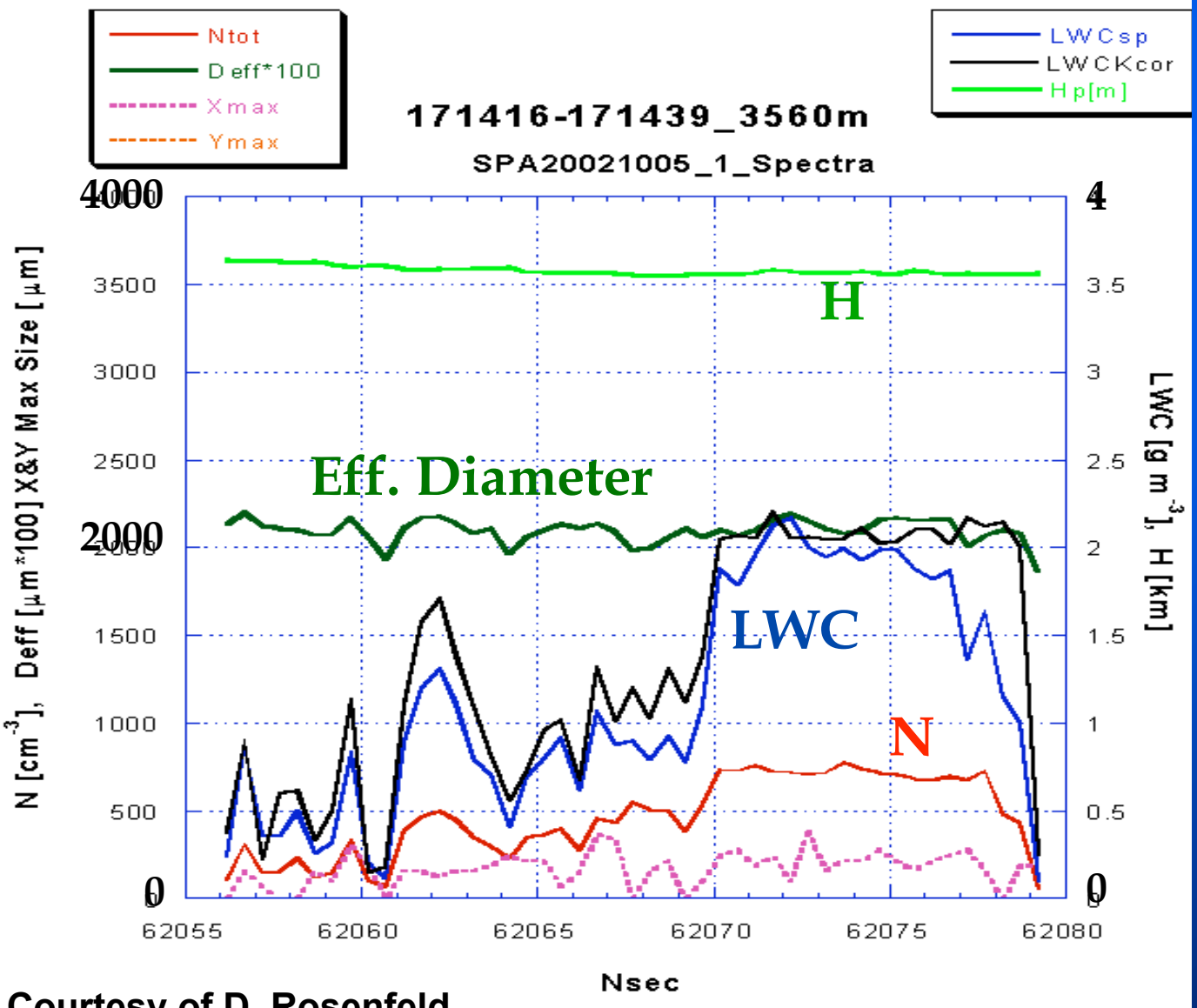
Histogram of Droplet Effective Radii as a Function of 2.1mm Reflectance Showing sensitivity for retrievals from cloud side



Effective Radius X Cloud Cross Section ???



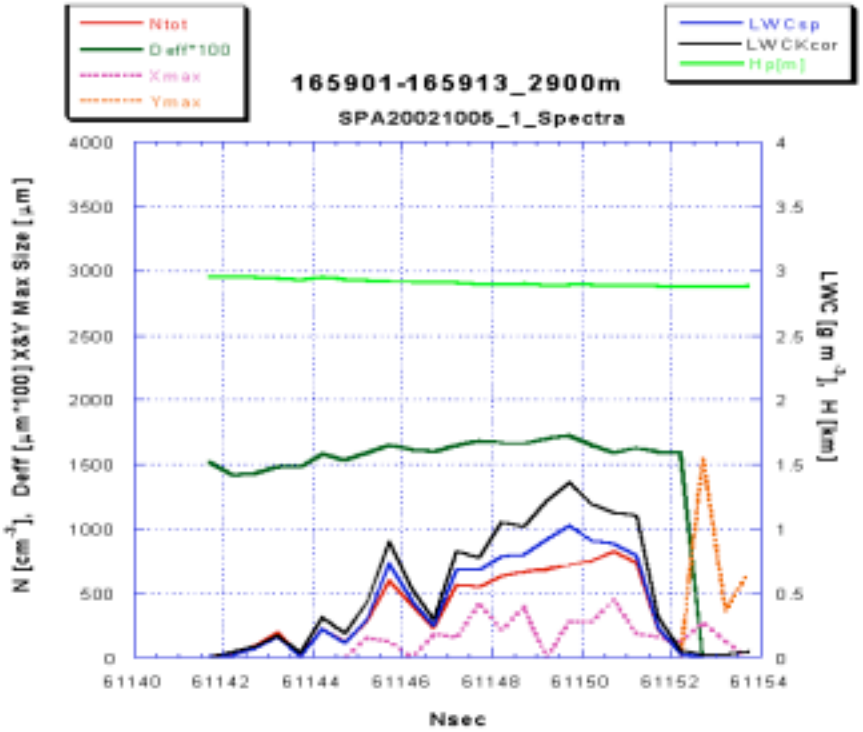
Effective Radius X Cloud Cross Section

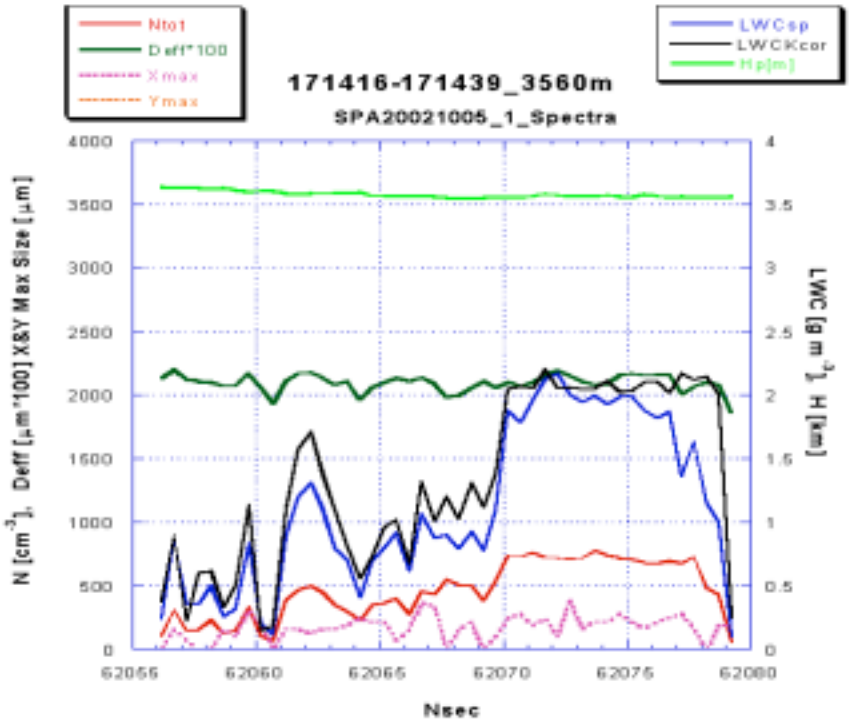


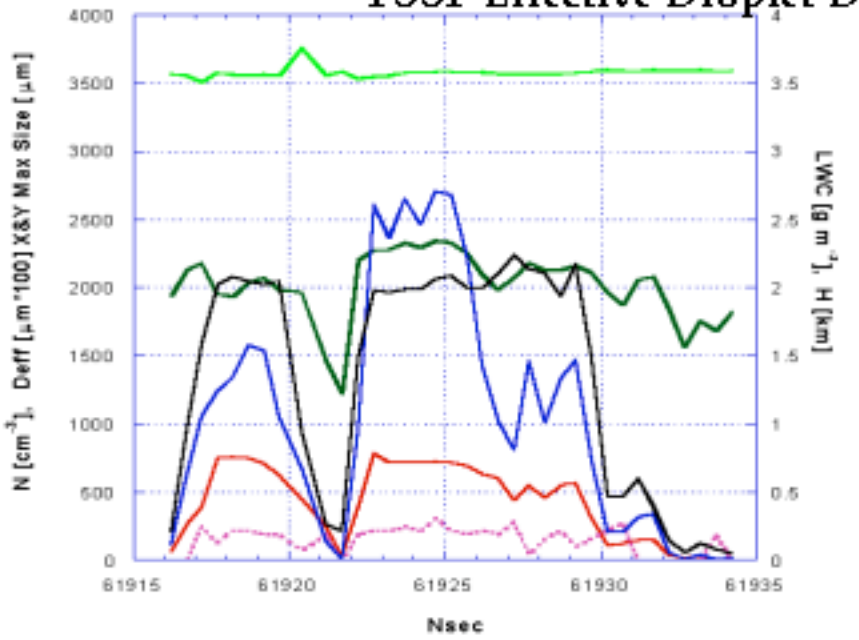
Courtesy of D. Rosenfeld

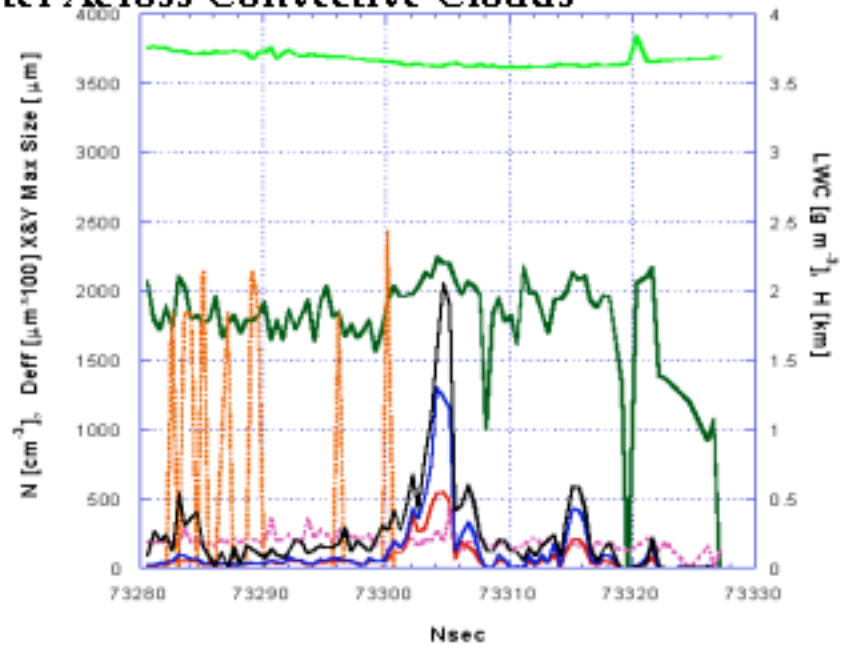
In several aircraft measurements using PSAP in the Amazon and Israel, including some precipitating clouds, the effective radius proved to be constant throughout the extension of the cloud though LWC content varied significantly.

FSSP Effective Droplet Diameter Across Convective Clouds







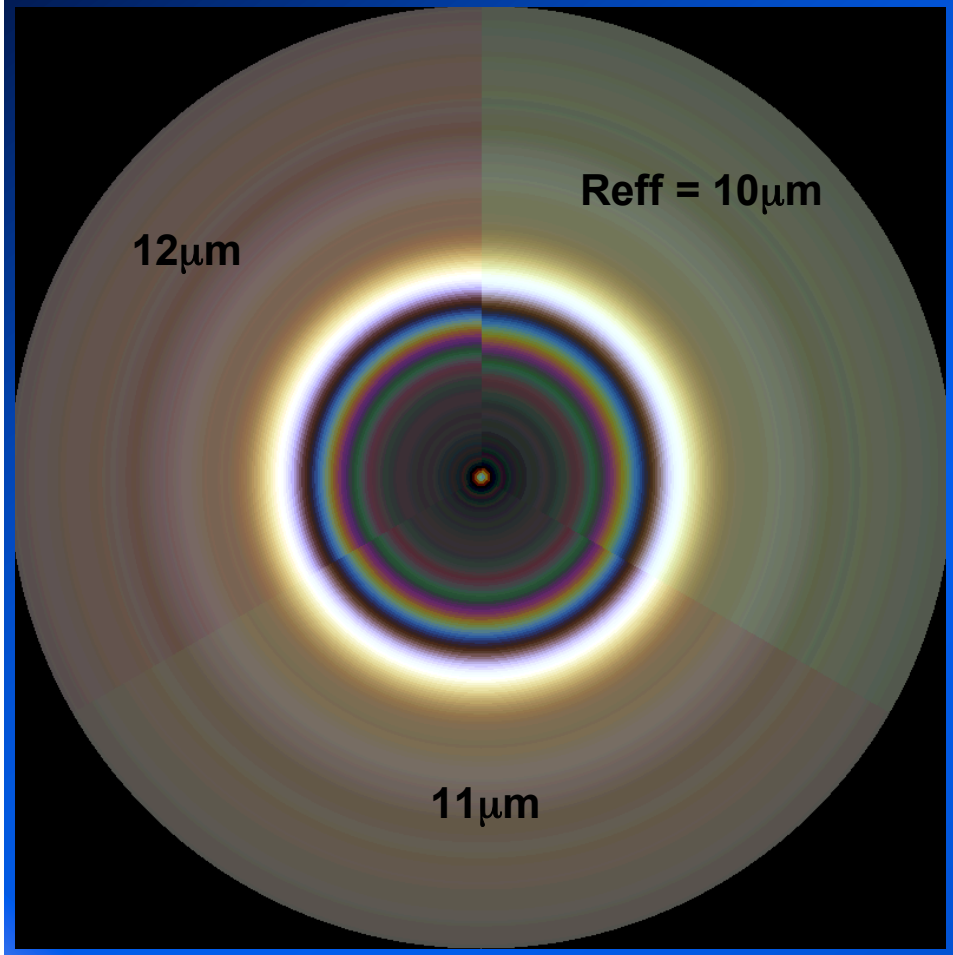


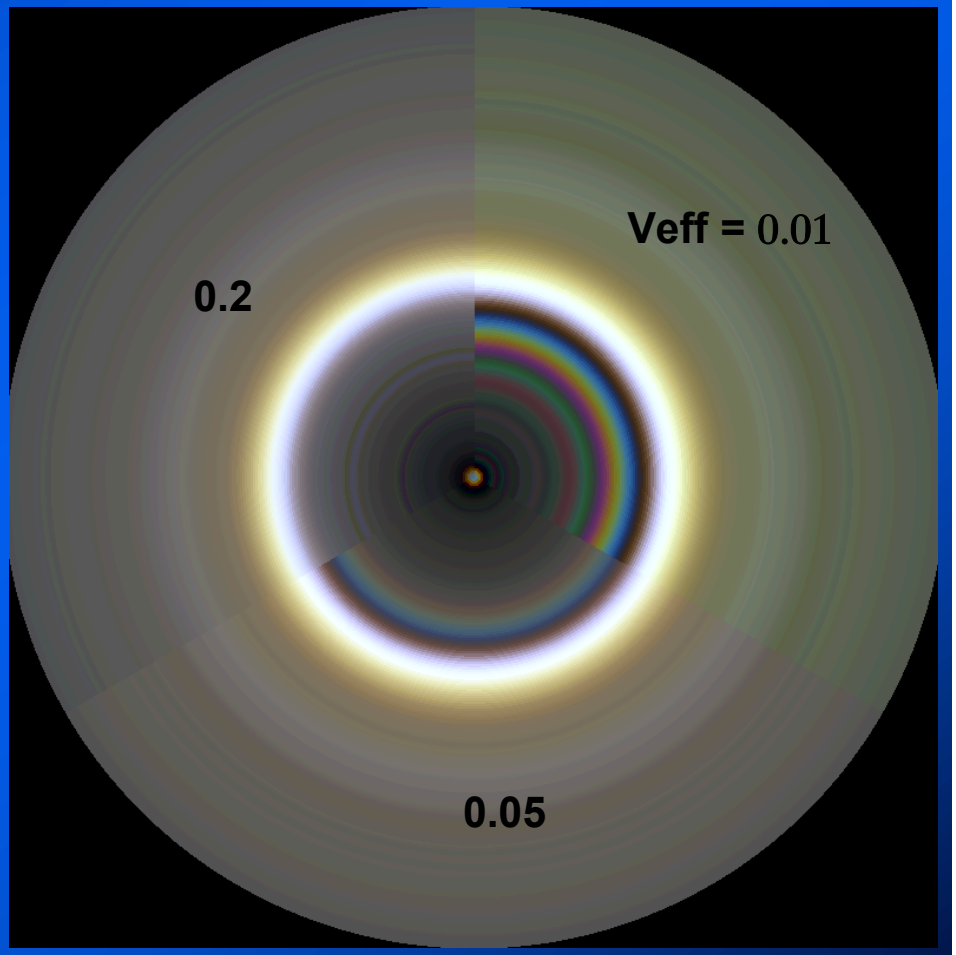
Unpolarized Cloud top reflectance

Cloudbow Measurements for Accurate Effective Radii and variance

- should provide effective radius retrievals at least one order of magnitude more accurate than current methods, in addition to unprecedented measurements of the width of the droplet distribution.

Cloudbow – Sensitivity to Droplet Effective Radius and Effective variance

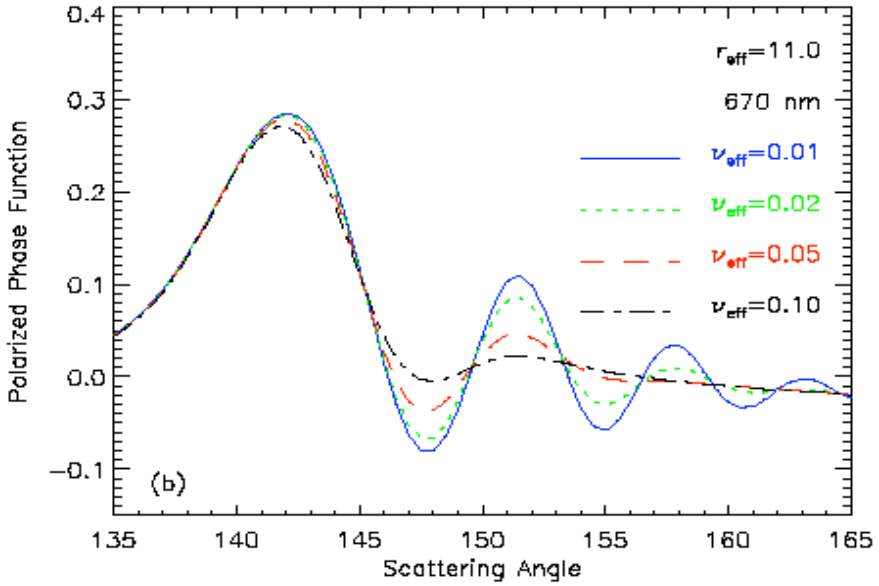


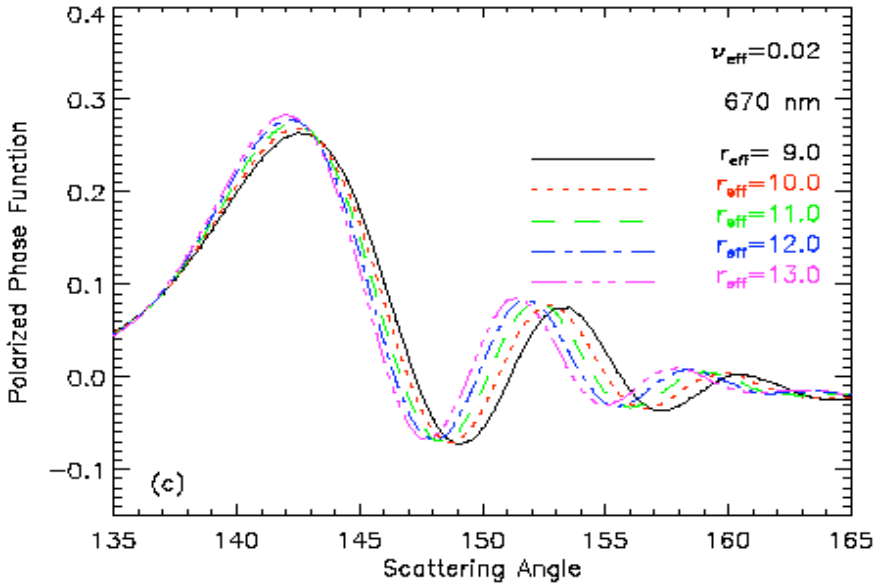


Polarized reflectance for clouds with different effective radii and effective variances

Cloud Droplet effective radius from polarization measurements

F-M. Breon, P. Goloub, 1998.





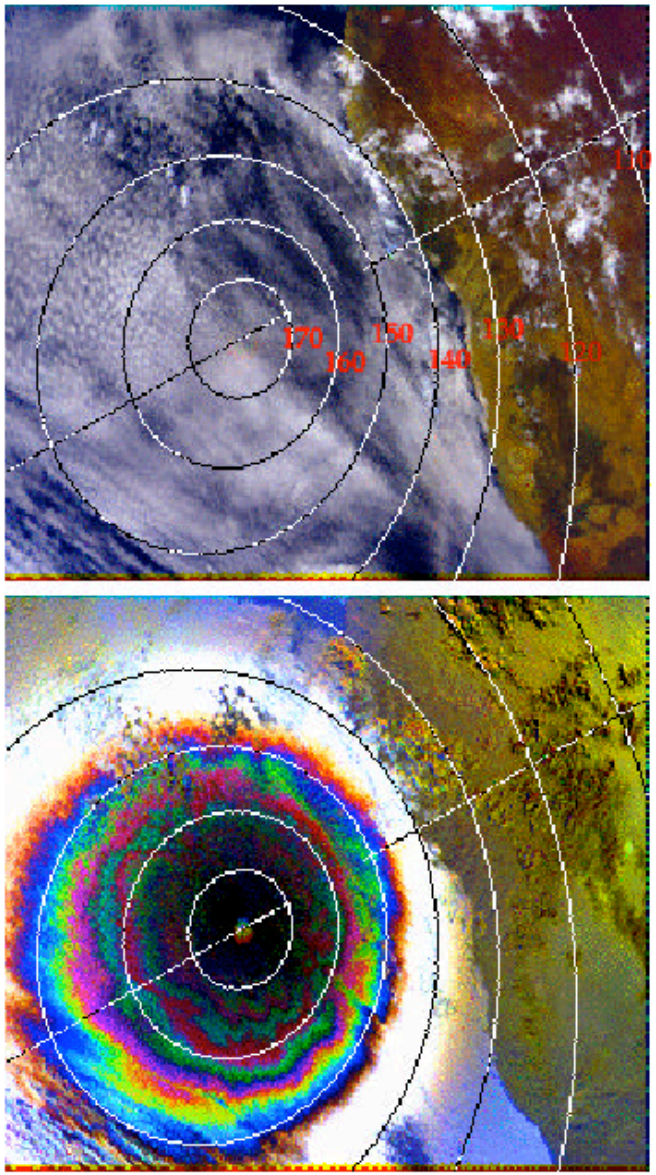
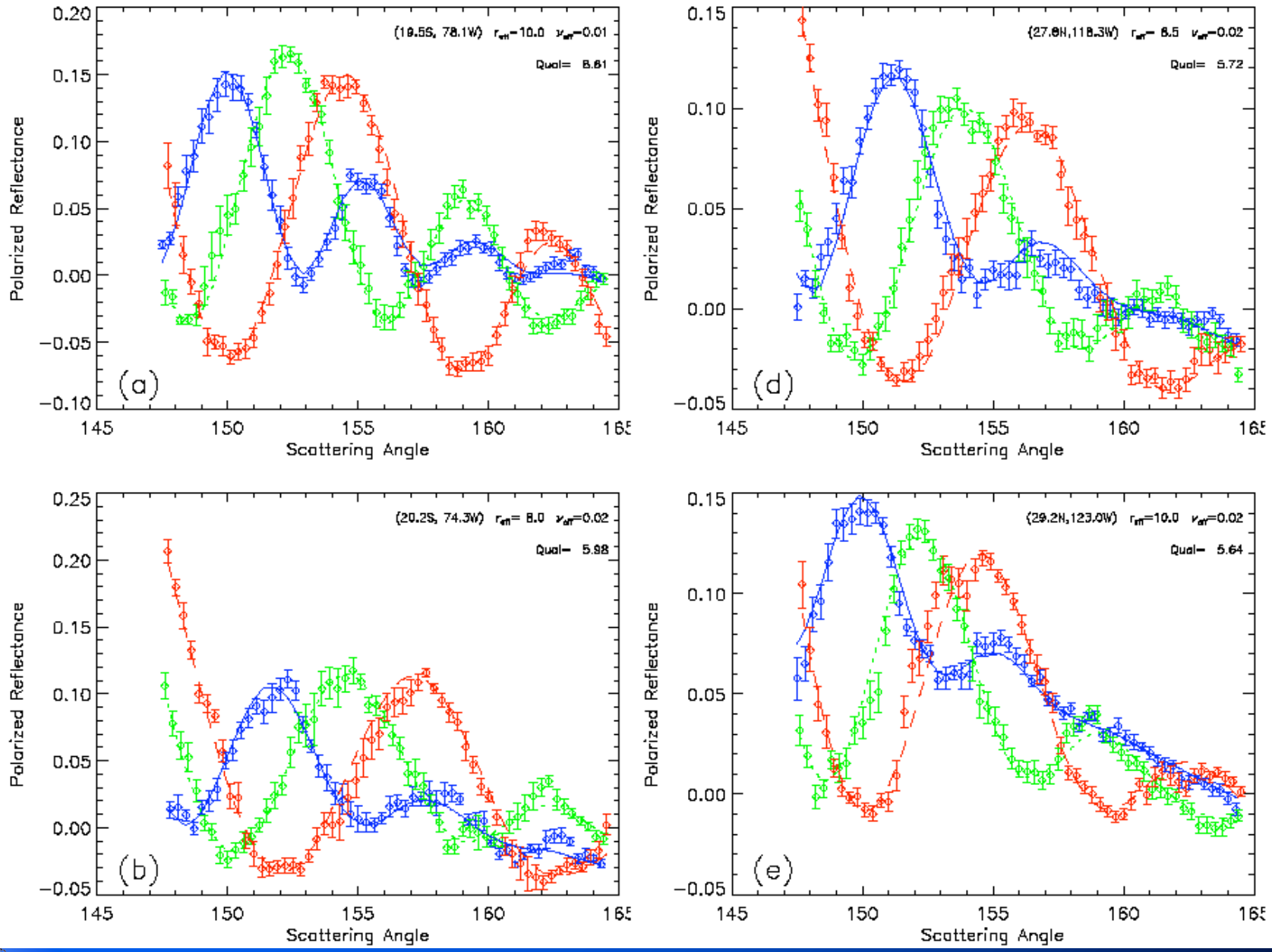


Figure 1. Three color composite (Blue : 0.43 µm, Green : 0.67 µm, Red : 0.86 µm) of POLDER measurements acquired by the CCD matrix over the Atlantic ocean and Southern Africa on Nov. 3rd, 1996. The top figure is for the total reflectance, whereas the bottom figure represents the polarized reflectance. The curved lines indicate the scattering angle in 10° increments (smaller radius line is for 170°). The straight line is the principal plane.



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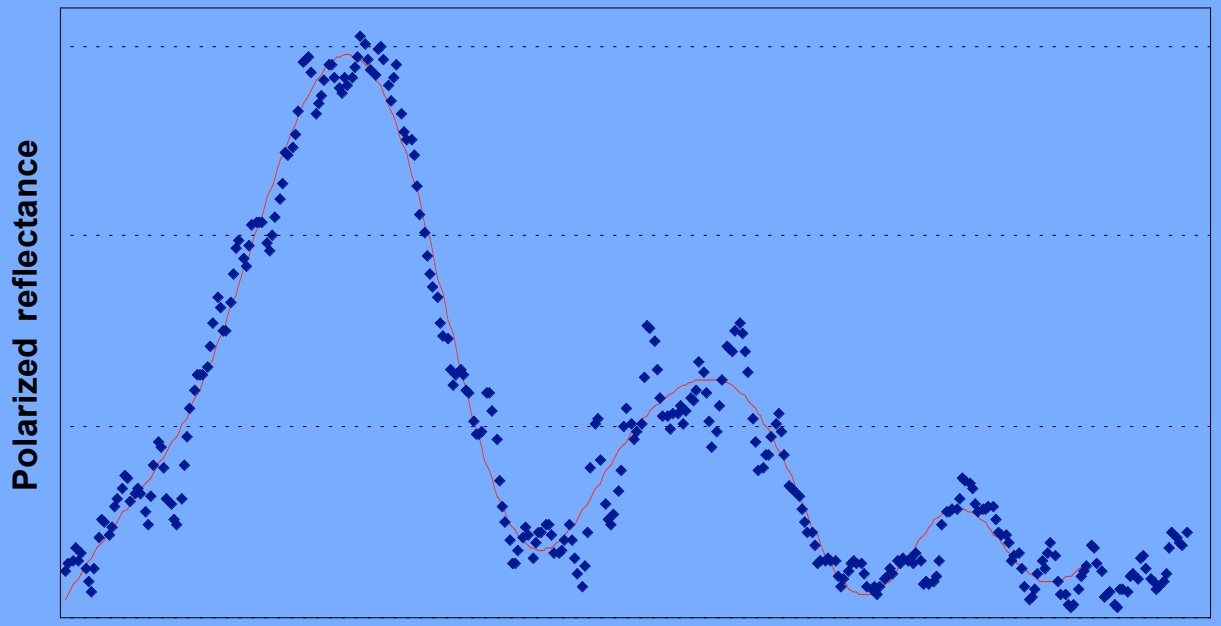
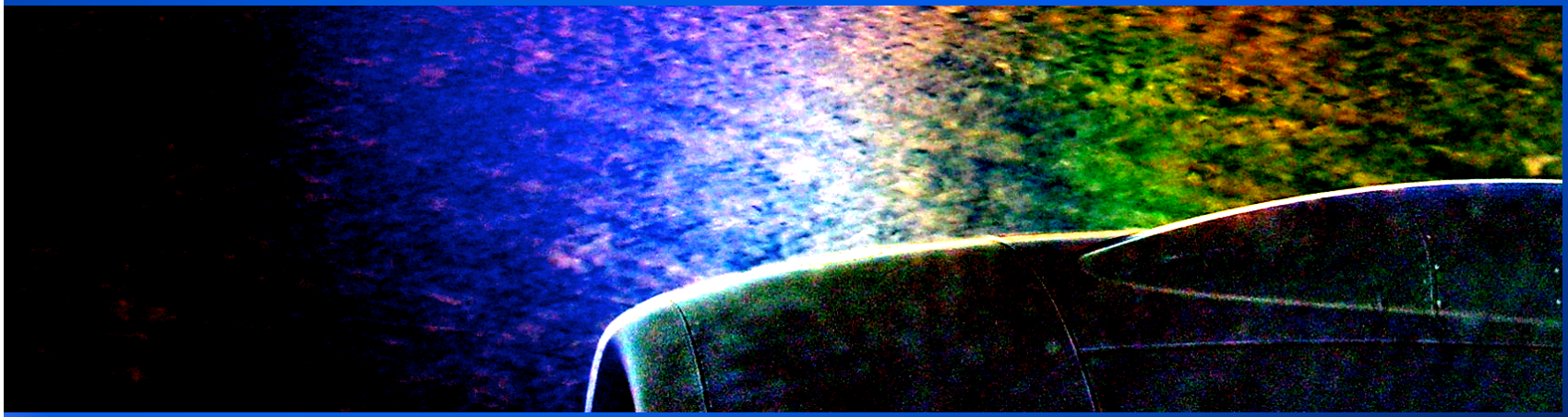
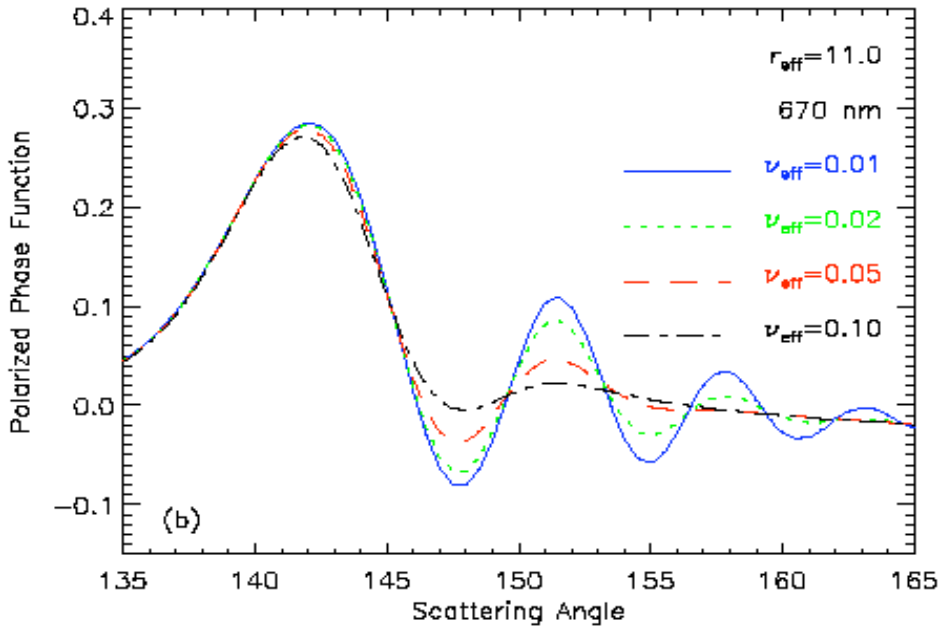
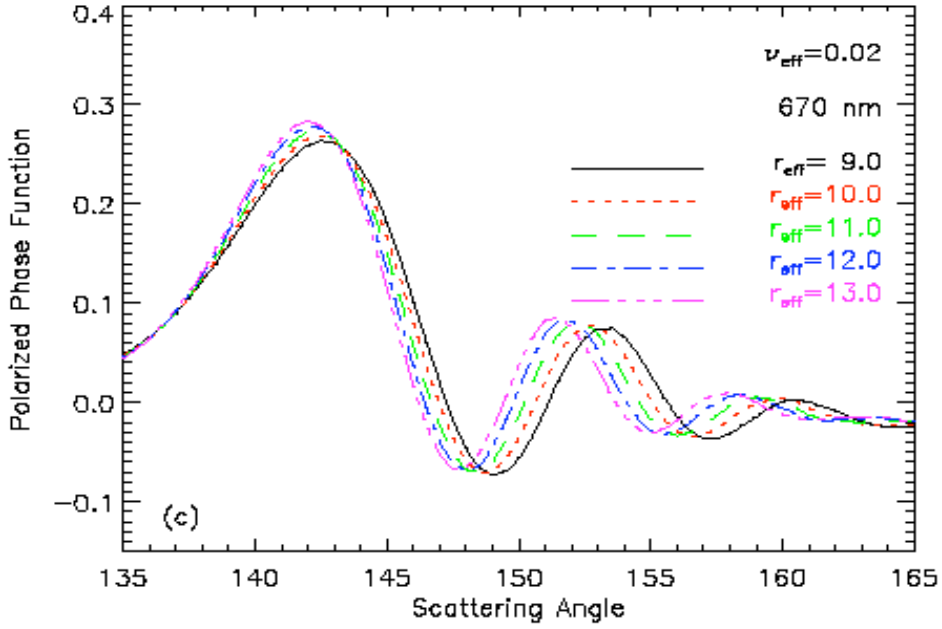
Cloud Bow measurements from Space with Polder
Breon and Boucher, submitted to IEEE 2005

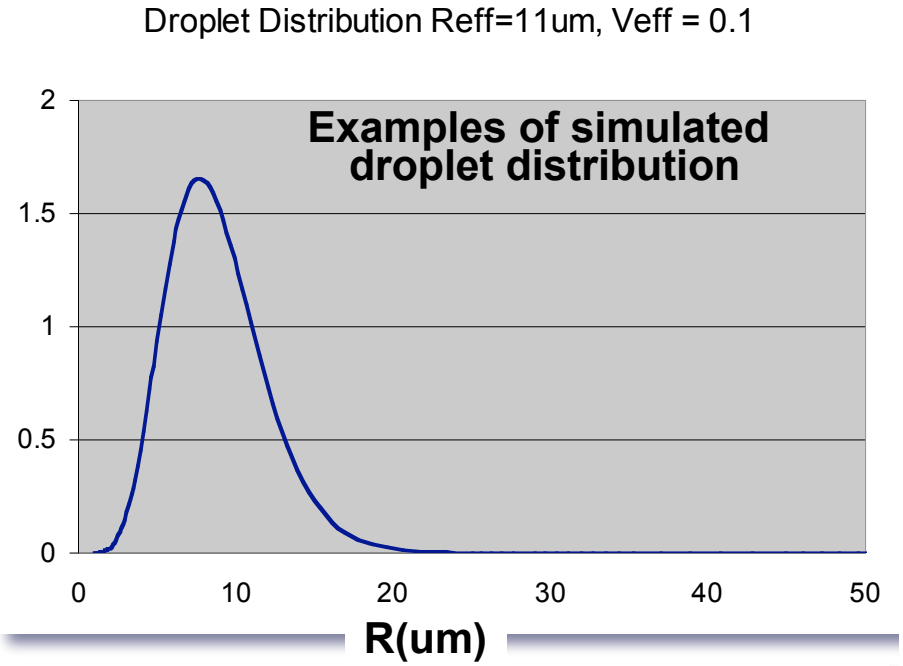
Rainbow Camera Prototype Measurement
Commercial Flight Beijing New York - August 14 2005











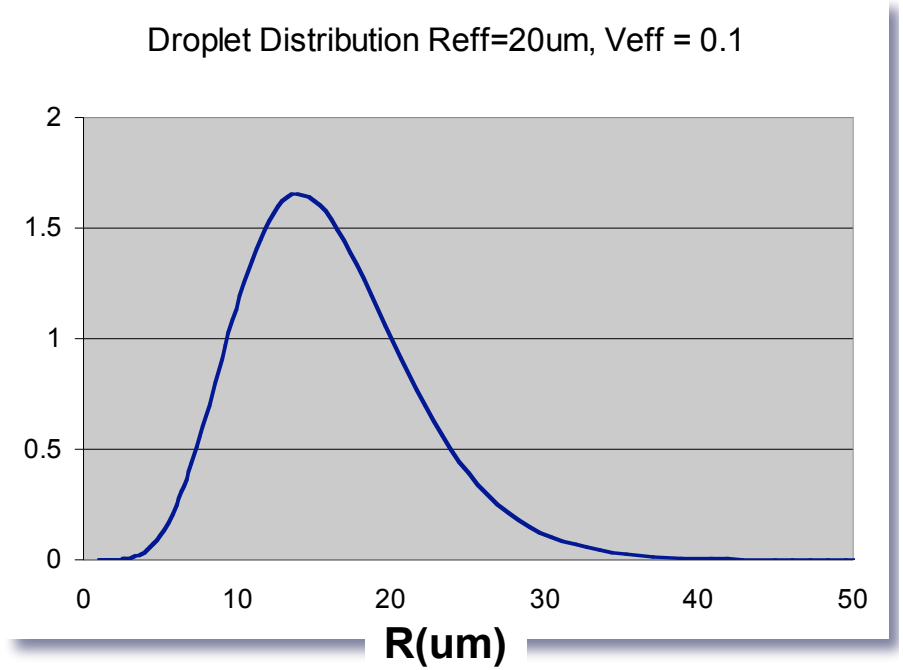
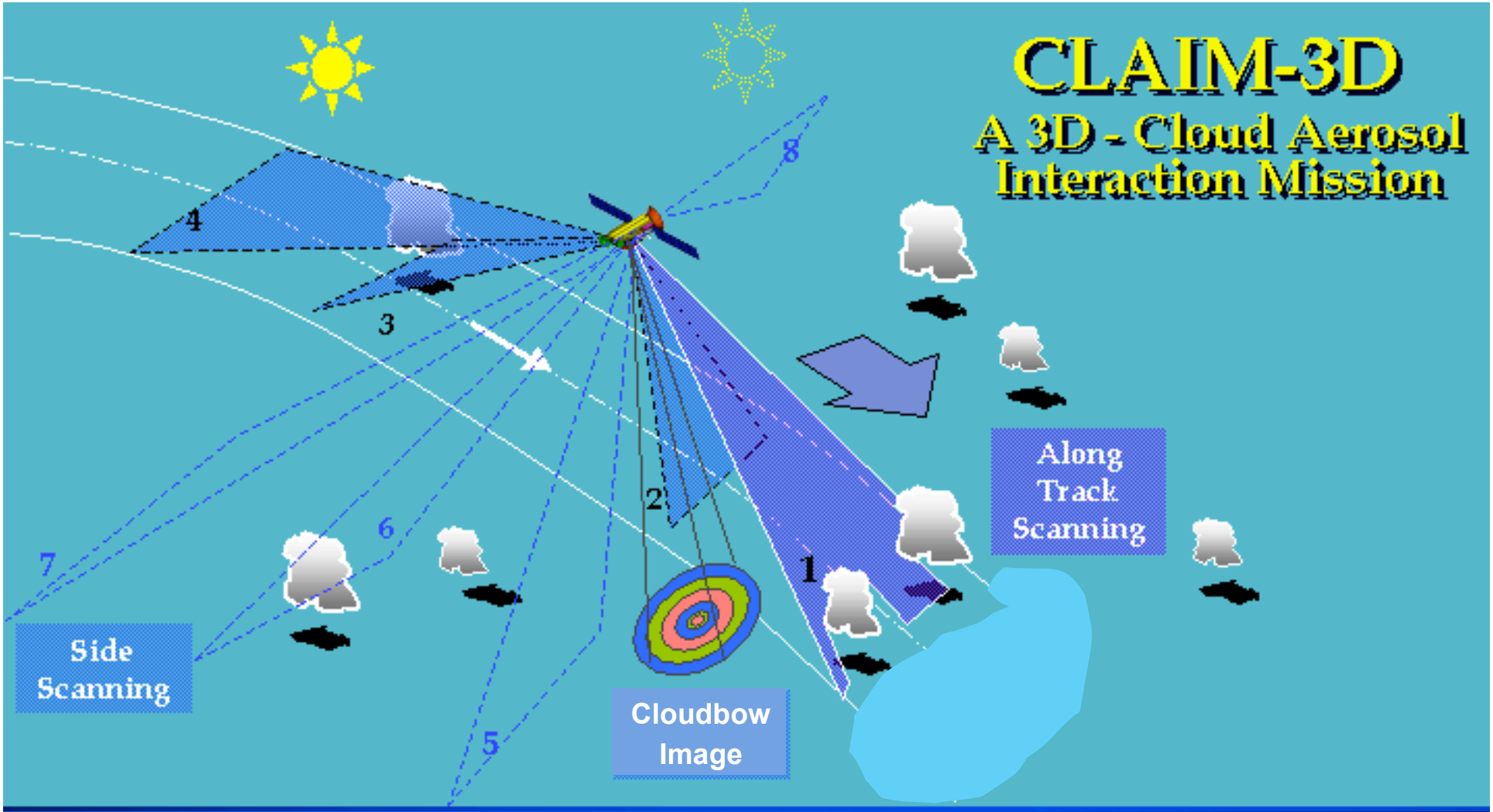


Figure 3: Polarized phase function as a function of the scattering angle for various effective



Important Features:

- Extended Wavelength Coverage UV–TIR
- Multi-Angle Viewing capability (for aerosols and cloudbow)
- Polarization
- High Spatial Resolution

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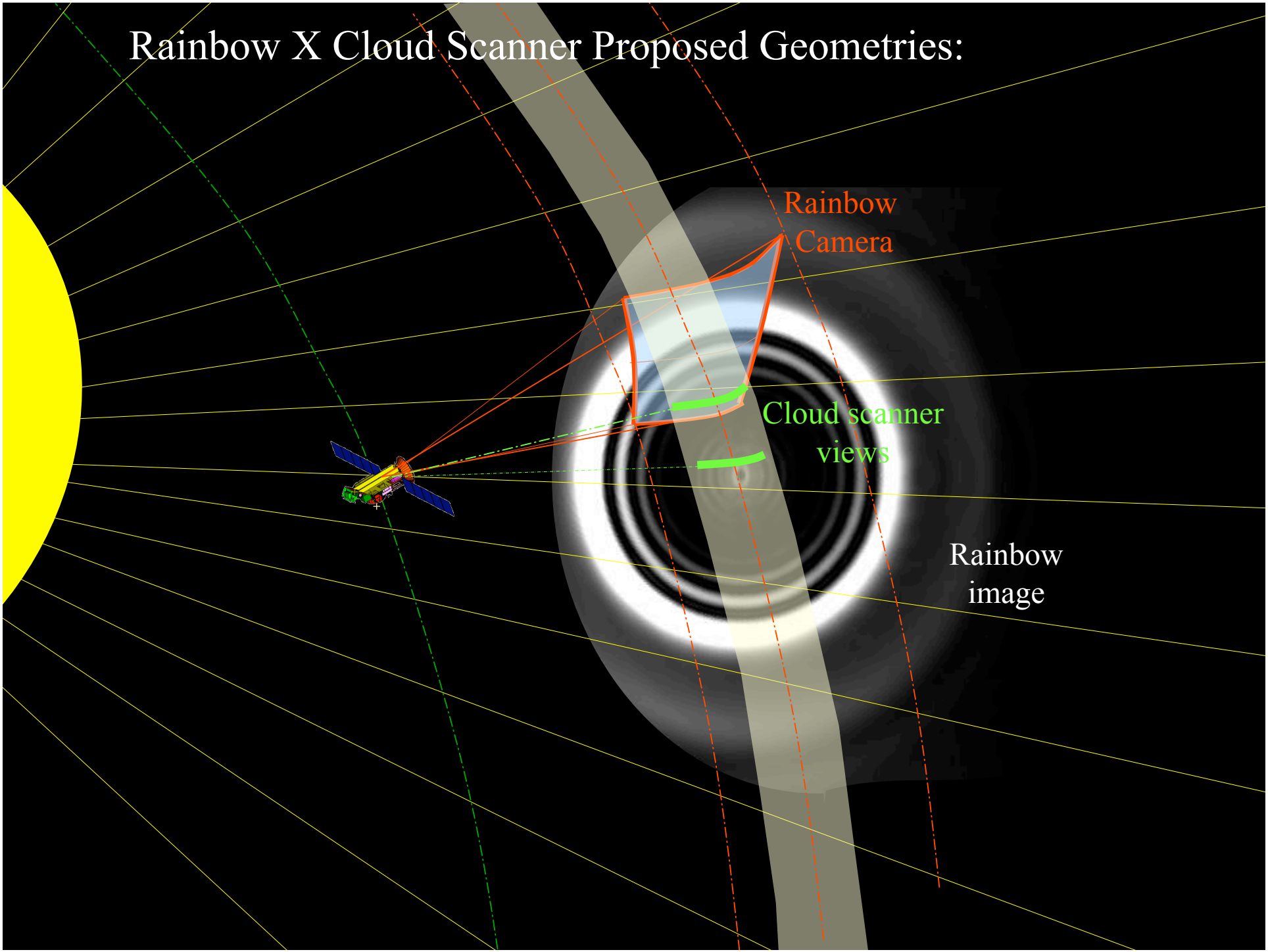

Rainbow X Cloud Scanner Proposed Geometries:
Rainbow
Camera
Cloud scanner
views
Rainbow
image

Backup Slides

Cloud Scanner Summary

- Measurements from cloud side provides instantaneous information on the vertical profile of cloud droplet microphysics and thermodynamics

- 3D effects from cloud side do not prevent relatively simple retrievals to be performed

Cloudbow Summary

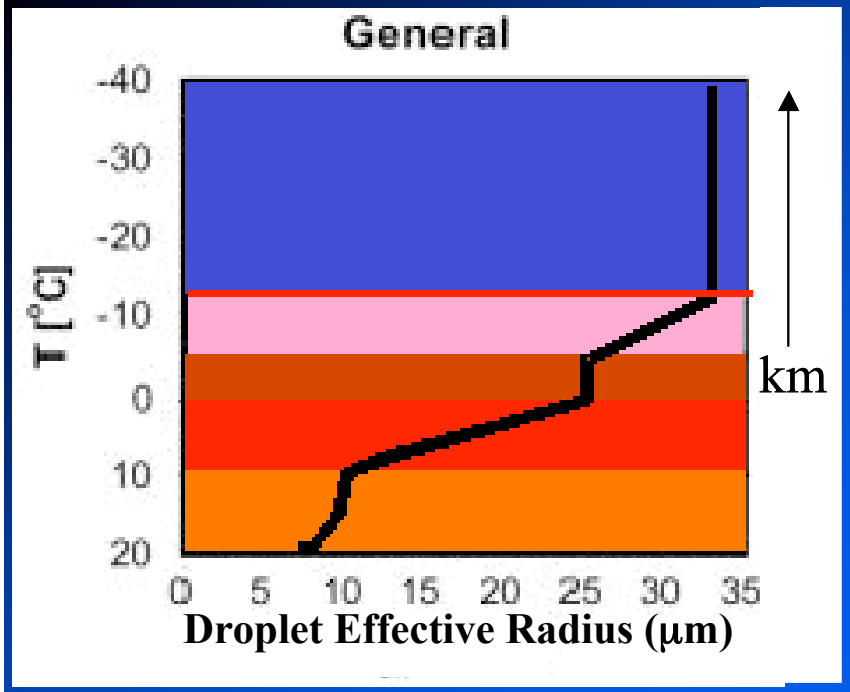
- The cloudbow measurements can be a simple and accurate method to retrieve cloud water droplet effective radius and effective variance.

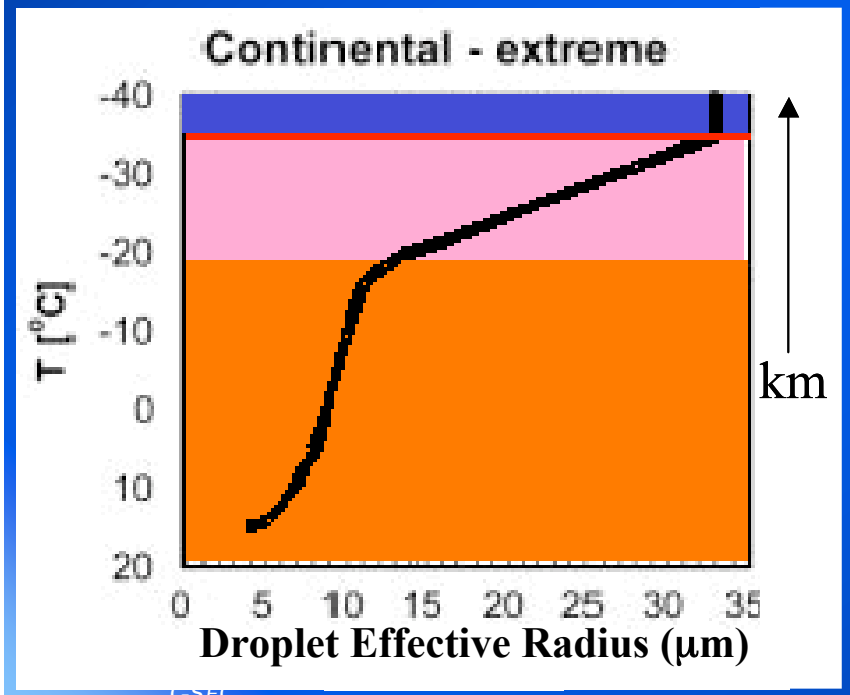
- These measurements can be easily performed from aircraft and/or space

- The polarized reflectance is much less sensitive to cloud 3D effects than the other traditional methods.

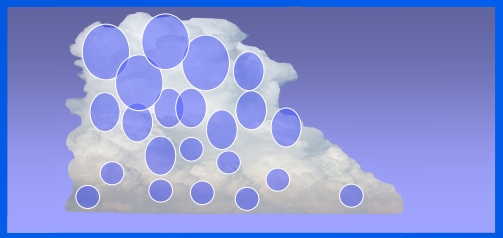
- Cloudbow measurements have different penetration than the NIR method for droplet size. Both methods combined can produce droplet size profile inside the cloud and be used as a measurement of entrainment.

A Simplified Conceptual Model:

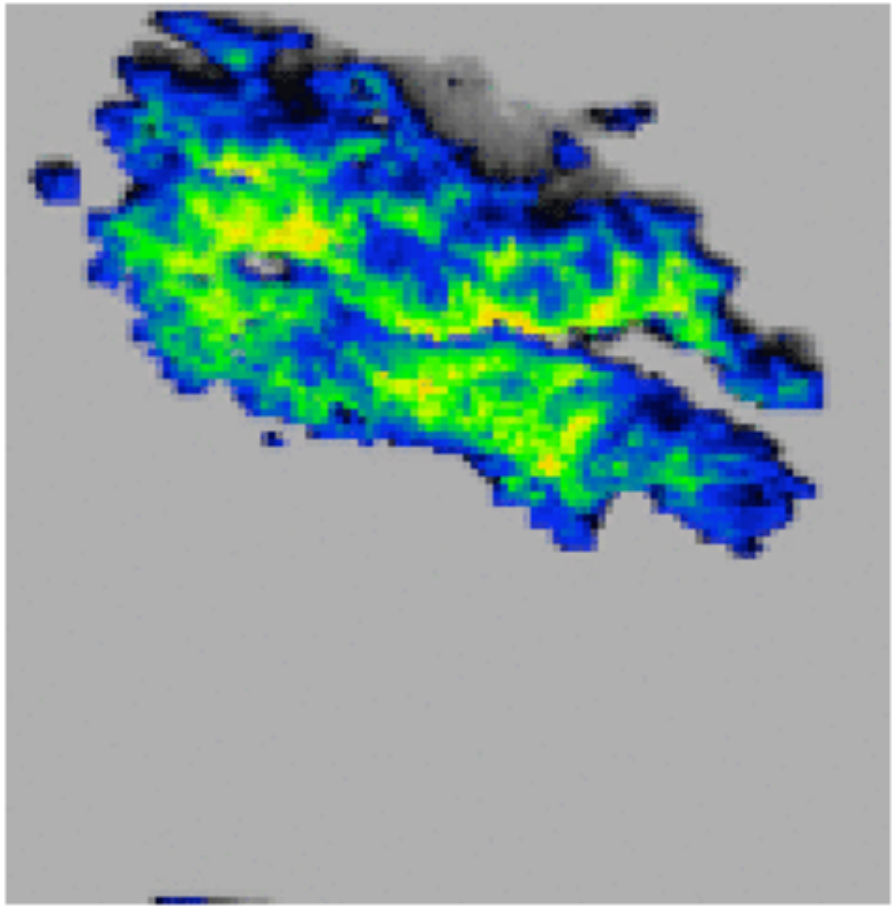


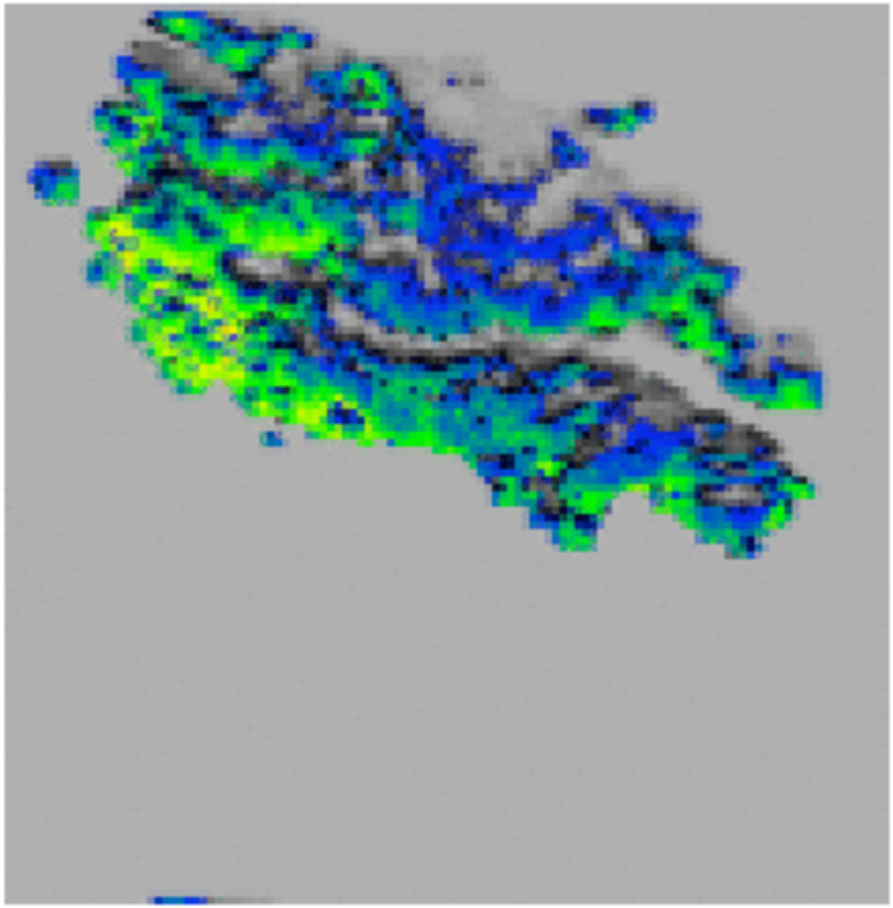


Clean



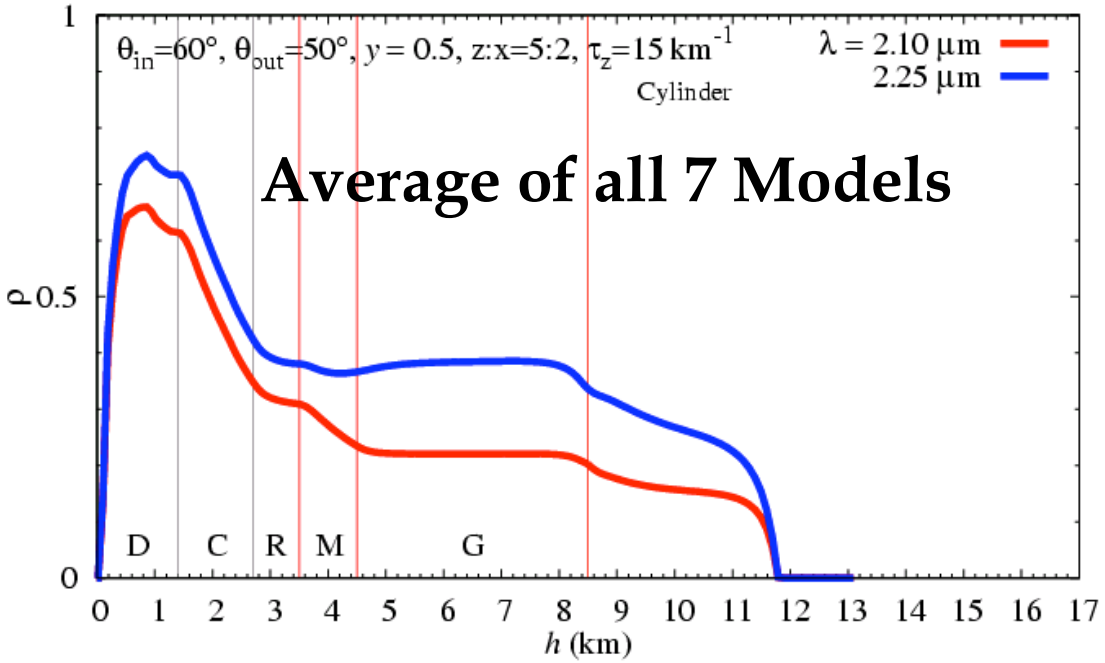
Polluted



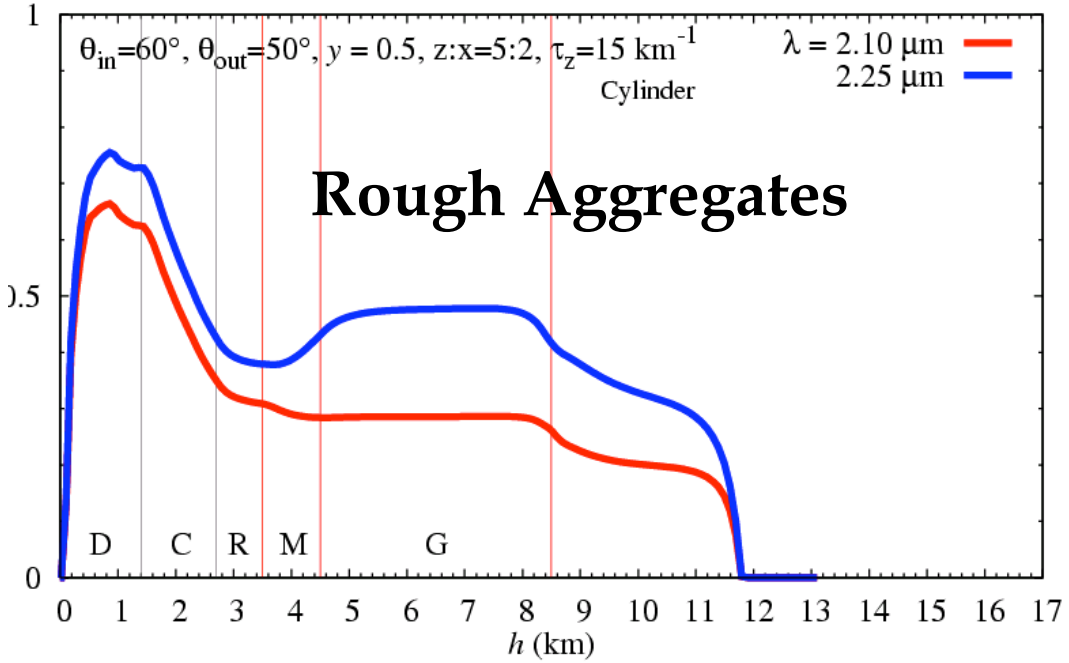


B. Mayer, T. Zinner

GSFC



Cloud Side and Top Reflectances for Several Ice Models



Science Proposed by CLAIM-3D

Full Characterization of Cloud Vertical Development and simultaneous Aerosol Microphysical Properties

- **Covers the Most Important Issues in Climate Forcing and Water Cycle today**

  Climate Change, Fresh Water Availability, Intensification of Thunderstorms, Stratospheric Transport, (…)

- **Not covered by any other existing or proposed mission today**

  MODIS, Glory, A-Train, European Missions, (…)

- Greenhouse = +2.5W/m2, Aerosols = -0.5W/m2

  New findings show N. Atlantic Aerosol Effect on Clouds/precipitation as large as = -10W/m2

- The response of a single GCM to CO2 doubling produce a 2 to 5C spread in predicted surface temperature change depending on how cloud processes are treated.

- Smoke Elevating the onset of Precipitation Reff change 14 – 9um ⇒ 1.5 to 6.5km
- Delay in precipitation/increase in cloud cover
- Shifting precipitation from Urban to remote areas
- Invigoration of updrafts, Intensification of Thunderstorms/Lightning, Production of Large Hail

- Increased overshoot cloud tops into stratosphere
- Transport of aerosols to higher layers/longer lifetime

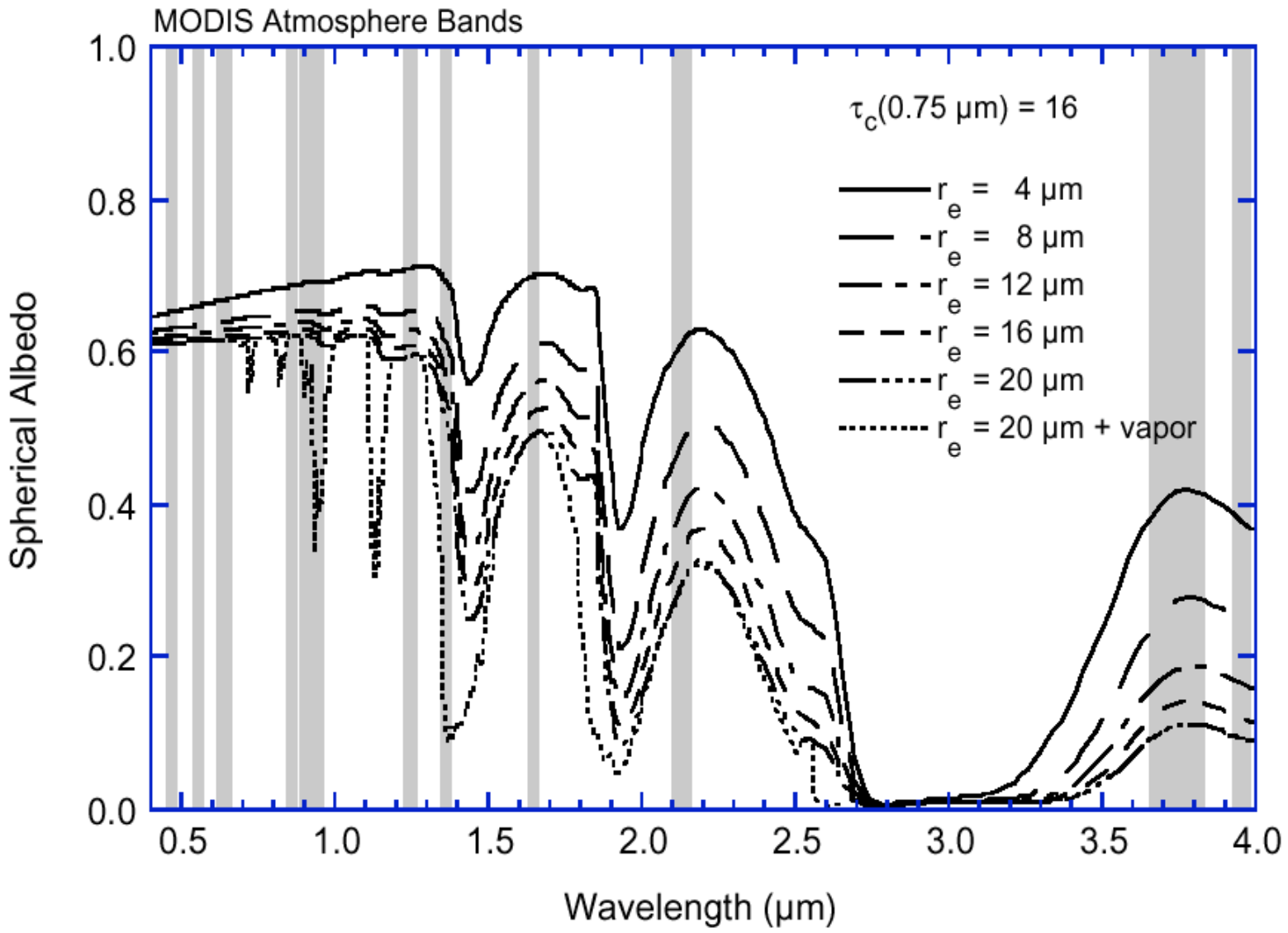
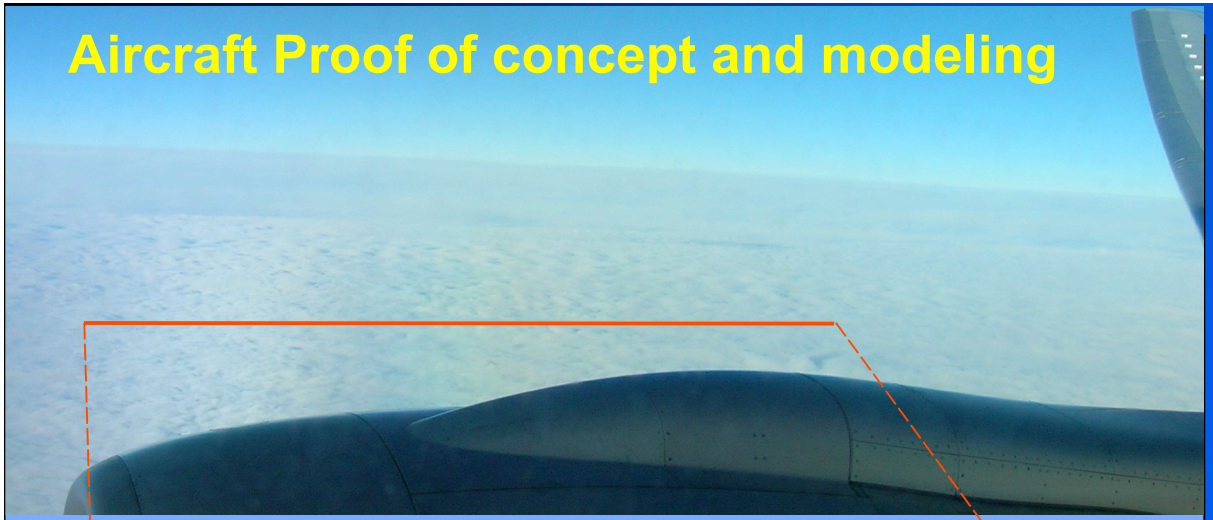
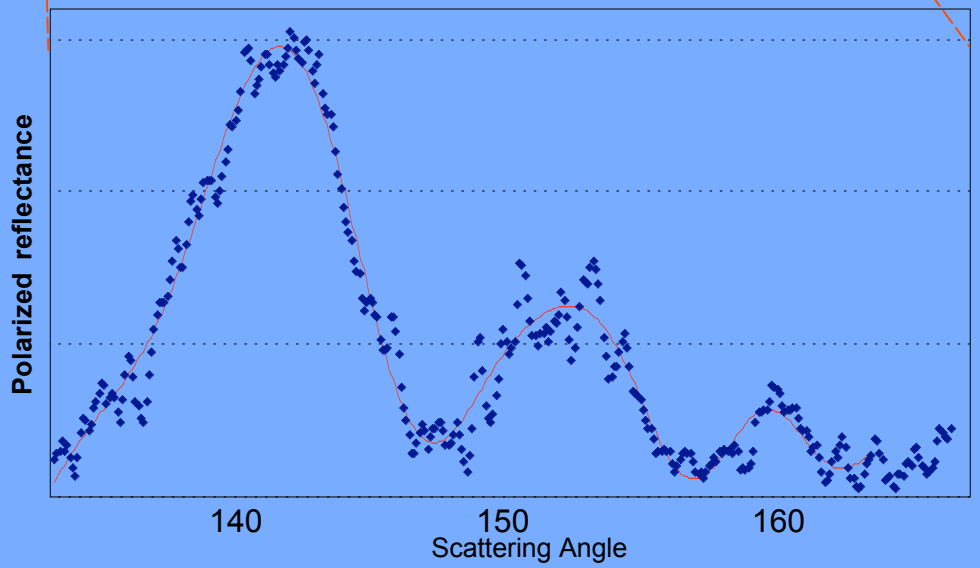


Figure 3. Cloud spherical albedo as a function of wavelength for selected values of the effective radius of cloud droplets. Results apply to water clouds having a modified gamma size distribution with an effective variance $v_e = 0.111$, cloud optical thickness $\tau_c(0.75\ \mu m) = 16$, and saturated water vapor $w_g = 0.45$ g cm^{-2}. The location and bandwidth of selected MODIS atmosphere bands are also shown in the figure.

King et. all 1997

Aircraft Proof of concept and modeling

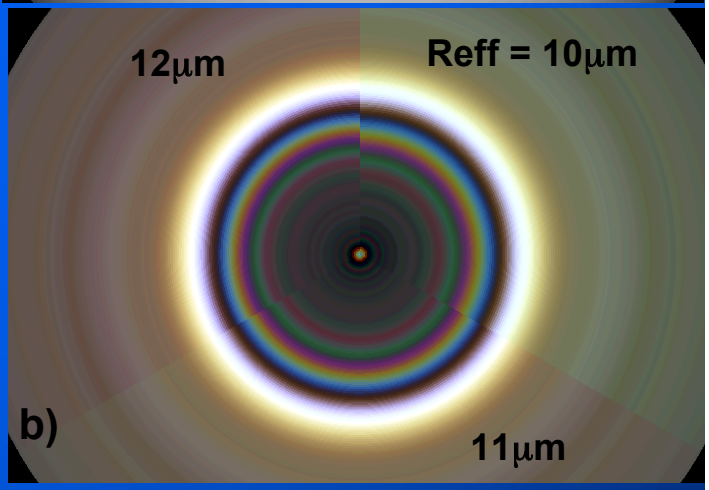


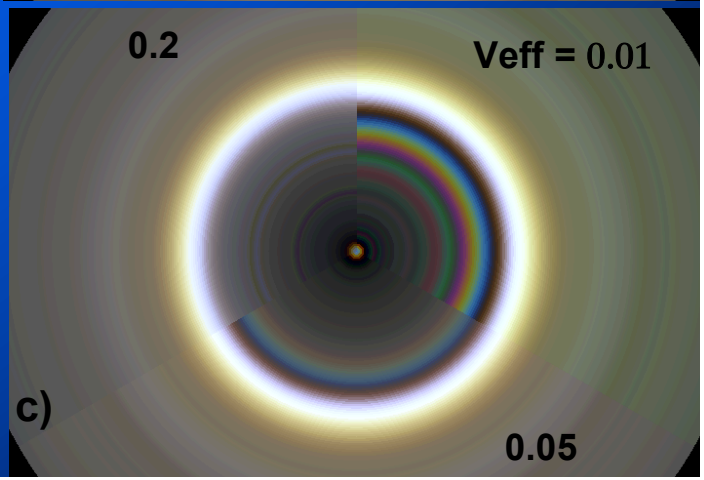


Top: Picture from Commercial Flight Beijing-New York on 14 Aug. 2005.

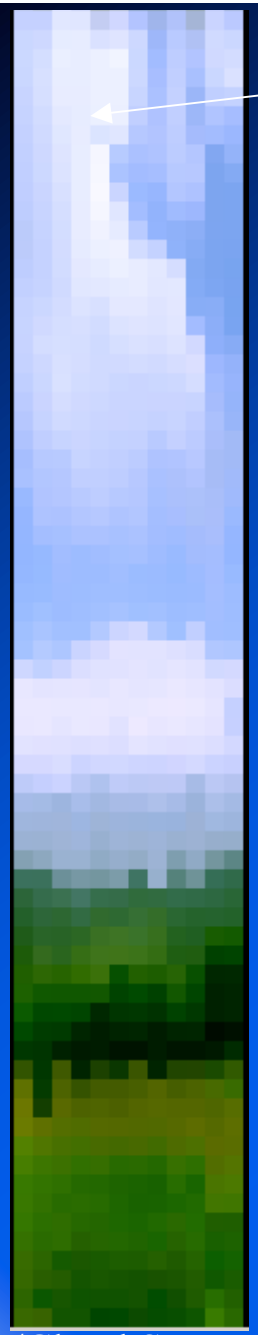
Right: Simulation of "cloudbow" showing a) unpolarized light just like we would see with our eyes; b) polarized reflectance showing sensitivity of the "cloudbow" to the cloud droplet radius; c) polarized reflectance showing sensitivity to the effective variance of the droplet size distribution.

Bottom: Profile of the measured polarized reflectance obtained following the red on the aircraft picture above.

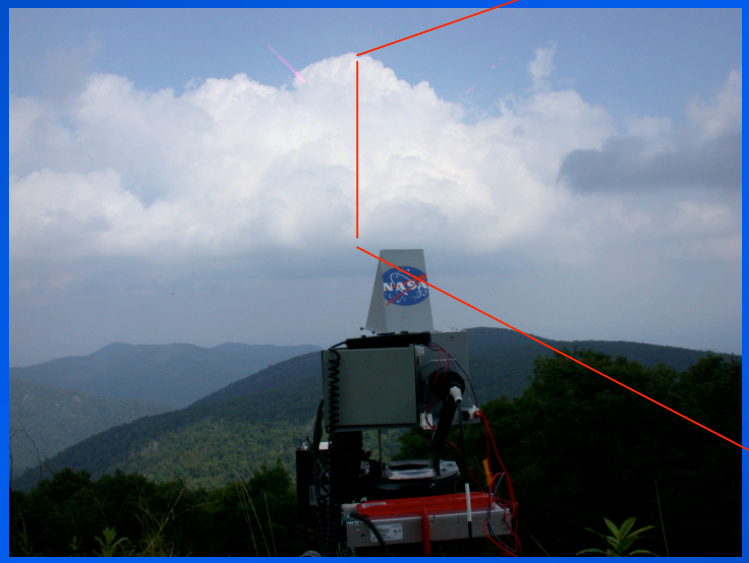




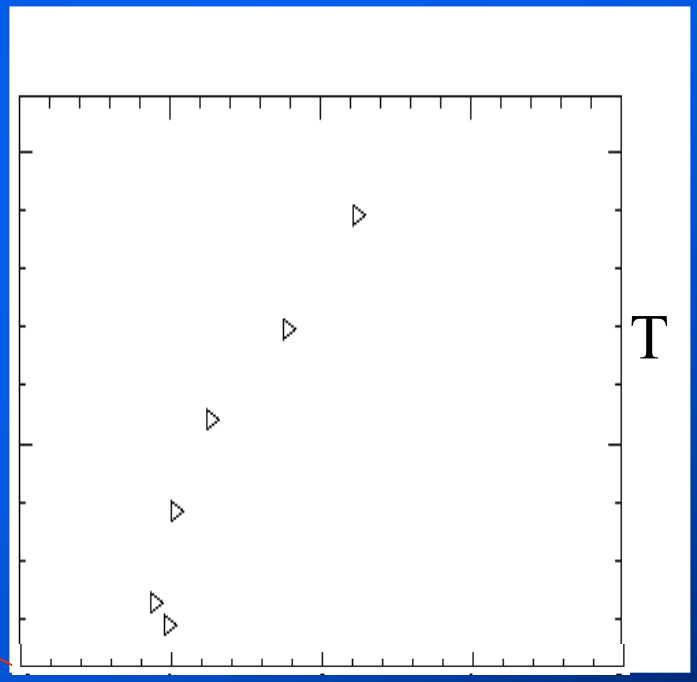
Cloud Scanner Measurements from Mountain Top Shenandoah 11 Sept. 2004



ASD Cloud Scanner RGB Image (120dg FOV)



Simultaneous Picture



Droplet Effective Radius
(arbitrary units)